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HAMILTON AREA RAPID TRANSIT STUDY

PHYSICAL FEASIBILITY REPORT

JULY 1970

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HAMILTON AREA RAPID TRANSIT STUDY

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BOOK 1

De Leuw, Cather

CONSULTING ENGINEERS

July 9, 1970

Mr. T. A. Rice
Chairman
Hamilton Transit Commission
18 Wentworth Street N
Hamilton, Ontario

Dear Mr. Rice:

The preparation of the attached two-volume Report was initiated by the Hamilton Transit Commission and authorized by the City of Hamilton and the Department of Highways, Ontario. The assignment was undertaken by our firm, in liaison with the Hamilton Transit Planning Committee and the Department of Highways, in accordance with the Terms of Reference for the Study.

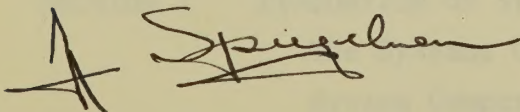
It was found that, with presently available design and construction techniques, it would be physically feasible to construct a rapid transit line to connect the four areas in Hamilton that were investigated, i.e., Mountain, Escarpment, Central and Bay Front Industrial Areas. Six alternative alignments were developed from which a selection can be made.

We gratefully acknowledge the assistance of your staff as well as that of the several City Departments and other Agencies. Their cooperation was a major contribution in the formulation of this Study.

We appreciate the opportunity to work on this project which is vitally important to the Hamilton Metropolitan Area and look forward to the day when your rapid transit service becomes an actuality.

Yours very truly,

DE LEUW, CATHER & COMPANY OF CANADA LIMITED



J. Spiegelman
Vice-President

JS:do

Att:

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SECTION 1

SUMMARY

1. Introduction

The City of Hamilton and the Hamilton Transit Commission retained De Leuw, Cather, consulting engineers, to undertake a limited physical study to ascertain if rapid transit is feasible and practicable for Hamilton and the general form in which rapid transit from the Mountain Area to the Lower City could be developed. The Terms of Reference for the Study are included in the appendices.

The main objective is to obtain information upon which policy decisions may be made with respect to the reservation and protection of the possible corridor, or corridors, with particular reference to the Central Business District, for the future construction of a rapid transit facility in Hamilton. Furthermore, essential input for the Official Plan of the City of Hamilton is whether rapid transit, in any form, is physically feasible and practicable for the City. This Study provides the Planning Commissioner with such information requisite to the preparation of the Official Plan.

The results of the Study are presented in two documents for convenient reference. Book 1 contains the descriptive text with supporting data assembled in the appendices. Book 2 contains the preliminary design drawings which illustrate the alternative alignments that were investigated.

2. Conclusions and Recommendations

The topography, geology, soils conditions and land-use development in the Hamilton Area impose significant constraints on the development of rapid transit routes for the proposed connection of the Mountain, Escarpment, Central and Bay Front Industrial Areas.

The Report concludes that design and construction techniques are presently available for the construction of a rapid transit line to connect the specified areas. A selection, for further study, can be made from the six feasible alternative alignments that have been developed. While no financial analysis has been undertaken, such selection will afford the basis on which fundamental policy decisions may now be considered.

Based on the rapid transit design and operational criteria, six alternative alignments were developed and found to be physically feasible:

(a) relevant to the geophysical problems and constraints and (b) for the accommodation of the rapid transit concepts evaluated in this Study.

The rapid transit design and operational criteria used for the development of the alternative alignments can be met by all concepts presently in operation, under development or likely to be developed. The final selection of the form of rapid transit for Hamilton should be left until after the basic decision has been reached to implement rapid transit in the City.

Alignments

A composite key plan, Exhibit 1, shows the following six alternative alignments that were developed:

Alternative 1 - See Exhibits 2 to 10

Commencing at a station at Fennell on the Mountain, an underground structure proceeds northerly along Upper James to the toe of the Escarpment, continues underground northerly on the east side of James to Young, then north-westerly under the T.H. & B. tracks along MacNab through Civic Square to curve easterly along Cannon. It then curves northerly and climbs to elevated structure over the yards and along Ferguson over the C.N.R. tracks, and curves easterly and northerly over Wellington to Burlington. Beyond this point the alignment is the same for all of the alternatives, i.e., easterly on elevated structure north of and generally parallel to Burlington, to terminate at a station located east of Kenilworth. Other locations for

potential stations are at James and St. Joseph's Drive, Civic Square, Cannon and Hughson, Ferguson and Barton, Wellington and Macaulay, Burlington and Wentworth, Burlington and Sherman, Burlington and Gage and Burlington and Ottawa.

Alternative 2 - See Exhibits 11 to 19

This alignment is the same as Alternative 1 except, northerly from Civic Square the underground structure continues along MacNab to a station at Cannon and is then offset to the west side of MacNab. It then climbs to elevated structure north of Barton, crosses over the C.N.R. tracks and curves easterly over to the north side of Burlington to continue on the alignment common to all of the alternatives at Victoria. Potential station locations would be the same as for Alternative 1 except the three stations on the Cannon-Ferguson-Wellington leg would be replaced with stations at MacNab and Cannon, MacNab and Macaulay, and Burlington and Ferguson.

Alternative 3 - See Exhibits 20 to 27

This alignment is underground along Upper James on the Mountain and curves easterly then northerly to emerge from the Escarpment in the vicinity of St. Joseph's and Ferguson. From this point it is on elevated structure and continues northerly along Ferguson along the same alignment developed for Alternative 4. Potential location of stations would be at Fennell and Upper James as for Alternatives 1 and 2 and, in the Lower City level would be as described for Alternative 4.

Alternative 4 - See Exhibits 28 to 35

This alignment is underground on the Mountain and follows along East 19th northerly from Fennell to curve westerly along Concession and then northerly to emerge from the Escarpment in the vicinity of St. Joseph's and Ferguson. Northerly from this point

it is on elevated structure along Ferguson, crosses over the T.H.& B. tracks and follows the railway tracks along Ferguson and curves easterly at Birge and northerly at Ferrie along the east side of Wellington. The line then curves easterly and crosses over to the north side of Burlington where it continues easterly from Victoria on the alignment that is common to all of the alternatives. Potential locations for stations would be: underground at Fennell and East 19th and at Inverness and East 19; elevated on Ferguson at Forest, King and Barton and at Wellington and Macaulay.

Alignment 5 - See Exhibits 36 to 44

This alignment is the same as Alternative 4 on the Mountain but remains and continues underground from the toe of the Escarpment until it reaches Barton. From westerly at Concession and Wellington it runs north westerly to the north side of Augusta at Hughson then curves westerly to pass under James then northerly along MacNab to pass through the Civic Square. It then continues along the same alignment as Alternative 2. Potential station locations: on the Mountain, as for Alternative 4; between the Escarpment and the T.H.& B. tracks, in the block bounded by Forest, John, Young and Catharine; north of the T.H.& B. tracks, as for Alternative 2.

Alternative 6 - See Exhibits 45 to 53

This alignment is a combination of Alternatives 1 and 5. South from Civic Square it is the same as Alternative 5 and north from Civic Square it is the same as Alternative 1.

The following lengths of routes and numbers of potential station locations were developed for each alternative alignment:

Alternative 1 - 5.8 miles, 11 stations

Alternative 2 - 6.0 miles, 11 stations

Alternative 3 - 5.6 miles, 10 stations

Alternative 4 - 5.9 miles, 11 stations

Alternative 5 - 6.5 miles, 12 stations

Alternative 6 - 6.5 miles, 12 stations

Rapid Transit Concepts

Five basic forms of rapid transit were evaluated and were considered in the development of criteria for route location in the Study. The systems considered were:

- . Conventional Rail Rapid Transit
- . Westinghouse Transit Expressway
- . Tracked Air Cushion Vehicles (TACV)
- . Bus Rapid Transit
- . Monorails

The basic engineering feasibility of these systems has been demonstrated either in commercial service or with experimental passenger carrying prototypes, unlike some of the more exotic forms of transit which exist in conceptual form only. All five systems would provide service on the long steep gradients necessary to negotiate the 300 ft. high Escarpment in Hamilton.

The recommended limiting gradient for conceptual design purposes is five percent or a rise of five feet for every one hundred feet of horizontal distance. This is based on the known operating characteristics of the latest high performance steel wheel vehicles. These can maintain speeds of 20 to 30 miles per hour on a five percent grade without adopting novel surface treatment or propulsion methods which have not been thoroughly tested in practice. Power consumption on a five percent gradient is double that required for similar operation on a level track.

In theory, steeper gradients are possible with all systems by using sophisticated propulsion technique and special surface treatment, to improve adhesion. These promising techniques could improve on the route up the Escarpment by providing greater flexibility in station location and by reducing the depth from the surface down to the station platforms. The limiting gradient for passenger comfort and safety on rapid transit vehicles is about ten percent; however, further study and experimentation is necessary to confirm that rapid transit performance and safety standards can be guaranteed before accepting gradients in excess of five percent as a proven design criteria.

The rubber tired vehicles such as Westinghouse Skybus, Monorails and Bus Rapid Transit offer better adhesion characteristics than steel wheeled vehicles but rail to surface pressures are lower. Thus good surface conditions must be guaranteed at all times to eliminate ice, oil, slick, etc., if rapid transit acceleration and braking performance is to be achieved on level tracks as well as on steep gradients. Power consumption will be higher than steel wheel on rail vehicles, ranging from 20 to 30 percent greater for rubber tired guided electric vehicles and 50 percent greater for bus type vehicles.

Tracked air cushion systems involve supporting the entire weight of the vehicle by lift motors which consume much more power than that required to overcome friction in vehicles supported on wheels.

However, with the virtual elimination of friction the power required for propulsion is significantly reduced. Propulsion methods include turbo-prop, fan jet or linear electric motors but so far only the latter is acceptable for urban use. It is estimated that lift and propulsion power consumption for TACV's will range between two and three times the power requirement for steel wheel vehicles.

The linear electric motor can be applied to wheeled or air cushion vehicles. Electro magnetic forces pull the primary energized part of the motor, fixed to the vehicle, along the secondary part of the motor which is a rail fixed to the track. There are no moving parts in the same sense as that of rotary electric motors. In the case of wheeled vehicles, problems associated with adhesion would be eliminated. The wheels would be used for support only and not for traction. Thus operation on steep gradients up to the limit of passenger comfort could be feasible. The linear motor is not in commercial application and in its present form is less efficient than conventional electric motors.

Continuing advances in technology can be expected to produce rapid transit vehicles incorporating improved adhesion or propulsion techniques and other features which may well have application in Hamilton, thus the final selection of a form of rapid transit for Hamilton should be left until after the basic decision has been reached to implement rapid transit in the city. At that time full advantage can be taken of technological advances and a detailed evaluation can be made of the engineering, economic and environmental aspects of the latest systems for an overall rapid transit network in Hamilton.

Structures

Each of the alignments developed in this Report include underground and elevated structures with transition sections between them.

Underground structures would be constructed by tunnelling methods in locations where the depth below ground would render construction by the cut and cover method uneconomical. South from the face of the Mountain to the southerly limit of the Study area, soil conditions indicate that tunnelling would be the preferred method since the rock appears to be sound. Based on preliminary investigations, a single semi-circular tunnel, that would accommodate the two tracks, is proposed for the running section through the Mountain. This would transition to two single track horseshoe-shaped tunnels approaching stations on the Mountain whose depth would require construction by tunnelling. If an alignment is selected where the station is relatively shallow and constructed by cut and cover, e.g., Alternative 3, there would be no need for the transition to two single tunnels. Rock tunnel structures would be lined with cast-in-place concrete.

North of the Escarpment, the line would be kept as close to the surface as practicable and the underground structures would be cast-in-place reinforced concrete rectangular rigid frames. These would be constructed by the cut and cover method. Other underground structures would include ventilation shafts, pumping stations and cross-over sections.

In the transition from underground to elevated the line would be in open cut and on embankment. The transitions would be of relatively short length and could be confined in width by the use of retaining walls instead of side slopes. This would be governed by property acquisition restrictions.

The elevated structures would be a cast-in-place continuous post tensioned concrete superstructure carried on single reinforced concrete piers. The foundations would be concrete filled steel cylinder piles which, in the Burlington Street area, it is expected would be driven to depths ranging from 80 to 100 feet below grade.

Costs

Preliminary cost estimates, based on current construction unit prices, for the alternative alignments are summarized in the following table. They have been itemized under five main structural components: Rock tunnel, Cut and cover, Elevated structure, Stations and Utilities.

Costs for property acquisition have not been included since only general alignments were developed for the purposes of this Study. As a rough guide, it would be feasible to consider that property costs would range from five to ten percent of the total costs tabulated for each alternative.

Trackwork, signals, control systems, vehicles and traction power installations have not been included since these would be governed by the concept selected. Again as a rough guide, excluding vehicles, the cost per mile for these items for conventional rail rapid transit would be in the order of two million dollars per mile.

In the preliminary cost estimates, no allowance is included for escalation. Once more as a rough guide, it would be feasible to consider five percent per year for expected escalation.

Design Modifications

This Study was mainly directed at determining the physical feasibility of implementing rapid transit to overcome the main problem of access from the Mountain through the Central Business to the Bay Front Industrial Areas. Concurrently, the general form in which rapid transit could be developed from the Mountain to the Lower City was investigated. The findings outlined herein tend to be conservative due to a relatively broad approach in which the development of specific details was not undertaken; this in order to afford a reasonable number of feasible options for future consideration.

SUMMARY OF STRUCTURAL COSTS

Alt. Lines.	RUNNING SECTION (BETWEEN STATIONS)										TOTALS	
	ROCK TUNNEL Lin.Ft. \$ Thous.	CUT & COVER Lin.Ft. \$ Thous.	ELEVATED STRUC. Lin.Ft. \$ Thous.	STATIONS No. \$ Thous.	UTILITIES \$ Thous.	Lin.Ft.	Miles	\$	Thous.			
1	3730	8,580.	6190	17,800.	17,110	16,330.	11	25,500.	2,660.	30,550	5.8	70,870.
2	3730	8,580.	6040	17,370.	18,310	17,480.	11	25,500.	2,650.	31,600	6.0	71,580.
3	4600	10,580.	530	1,220.	21,270	20,300.	10	20,000.	380.	29,600	5.6	52,480.
4	5230	12,030.	930	2,140.	21,220	20,250.	11	22,880.	480.	30,900	5.9	57,780.
5	6230	14,330.	6970	19,710.	18,310	17,480.	12	27,500.	3,150.	35,350	6.7	82,170.
6	6230	14,330.	7120	20,140.	17,110	16,330.	12	27,500.	3,120.	34,300	6.5	81,420.

1. The above costs are based on 1970 dollars with no allowance for escalation.

2. These costs include allowances for: station finish and equipment; escalators; temporary street decking and maintenance of traffic; utilities maintenance, relocation and restoration; pavement restoration; engineering and contingencies.

3. The above costs do not include: property acquisition; trackwork; signals; traction power; vehicles.

It is to be expected that it will be possible to make major modifications and refinements to the proposals included in this Study to the effect that the latest technological and planning developments may be incorporated in the design to provide the Hamilton Area with the ultimate in rapid transit service.

Course of Future Action

This limited physical feasibility study of rapid transit was prompted by the need to relieve the two major transportation problems as identified in the 1969 Report on Rapid Transit, prepared by the Transit Planning Work Group.

- (a) the necessity to be able to get people from the Lower Level to the Mountain at all times, in spite of icy roads and blocked access routes.
- (b) an effective plan which will remove or, at least, alleviate car parking in the north end industrial area.

Having confirmed the physical feasibility of rapid transit as a promising solution to these problems, a positive course of further action is required if rapid transit is to be implemented in Hamilton. The City must first confirm that rapid transit is an essential part of the future transportation system of the City. An organization should then be set up to establish and carry out the policies which will govern how the rapid transit system should be financed, designed, built and operated. These policies must be integrated with land-use planning and the overall transportation system for the City.

Financial participation by senior levels of government will also have major implications on the timing for rapid transit in the City and Region.

The remaining normal steps leading to implementation of rapid transit are as follows:

A. Feasibility Planning

This would determine the general feasibility of alternative projects to a sufficient degree to select the best solutions from alternatives such as presented in this Report. The factors to be considered would include not only physical feasibility and cost but also the wider implications of the City Official Plan and land-use development, overall urban economics and traffic prospects. The depth and timing of this planning work would depend to a very large degree on the amount of available land-use and traffic data and on how up-to-date it is.

B. Functional Planning

The last stage in the planning process, this would cover: type of system, design standards, geometrics, property requirements and other special investigations prior to design. It could also include detailed cost and traffic estimates and is usually undertaken when a project has been given a priority for early implementation. It would be a continuing process in extending the system.

C. Design

This would include the design and preparation of contract plans and documents for construction of the line, supply of vehicles and other items for the system. It too would be part of a continuing process to match the rate of development of the system.

D. Construction

This includes construction of the lines and stations and building the vehicles.

E. Operational Implementation

This includes training and extensive testing of the signal systems and vehicles.

The minimum time to implement rapid transit from the conceptual stage until service is initiated in Hamilton could be in the order of seven to ten years, if experience elsewhere is any guide. It is evident that the community is developing rapidly and there is a pressing need to move ahead with planning at the earliest possible time to identify and direct growth to the corridors and nodes, yet protect the right-of-way for future rapid routes. It will also have the major benefit of attracting development to the rapid transit corridors, even before the system goes into operation, with a consequent improvement in passenger prospects at the time of commencement of service.

SECTION 2

STUDY PROCEDURE

At the outset a Work Flow Plan, Figure 1, was formulated for the purpose of programming and monitoring the progress of the Study. During the course of the Study it was found necessary to make minor modifications to the programme with respect to timing. This was done without altering the content of the activities.

The Hamilton Rapid Transit Planning Committee and a representative of the Department of Highways attended several meetings at which interim reports, prepared by the Consulting Engineers, were presented and discussed. From the City of Hamilton there was representation from the Transit Commission, the Planning Department, the Traffic Department and the Engineering Department. One of the meetings included a field trip for on-site inspection of alternative alignments.

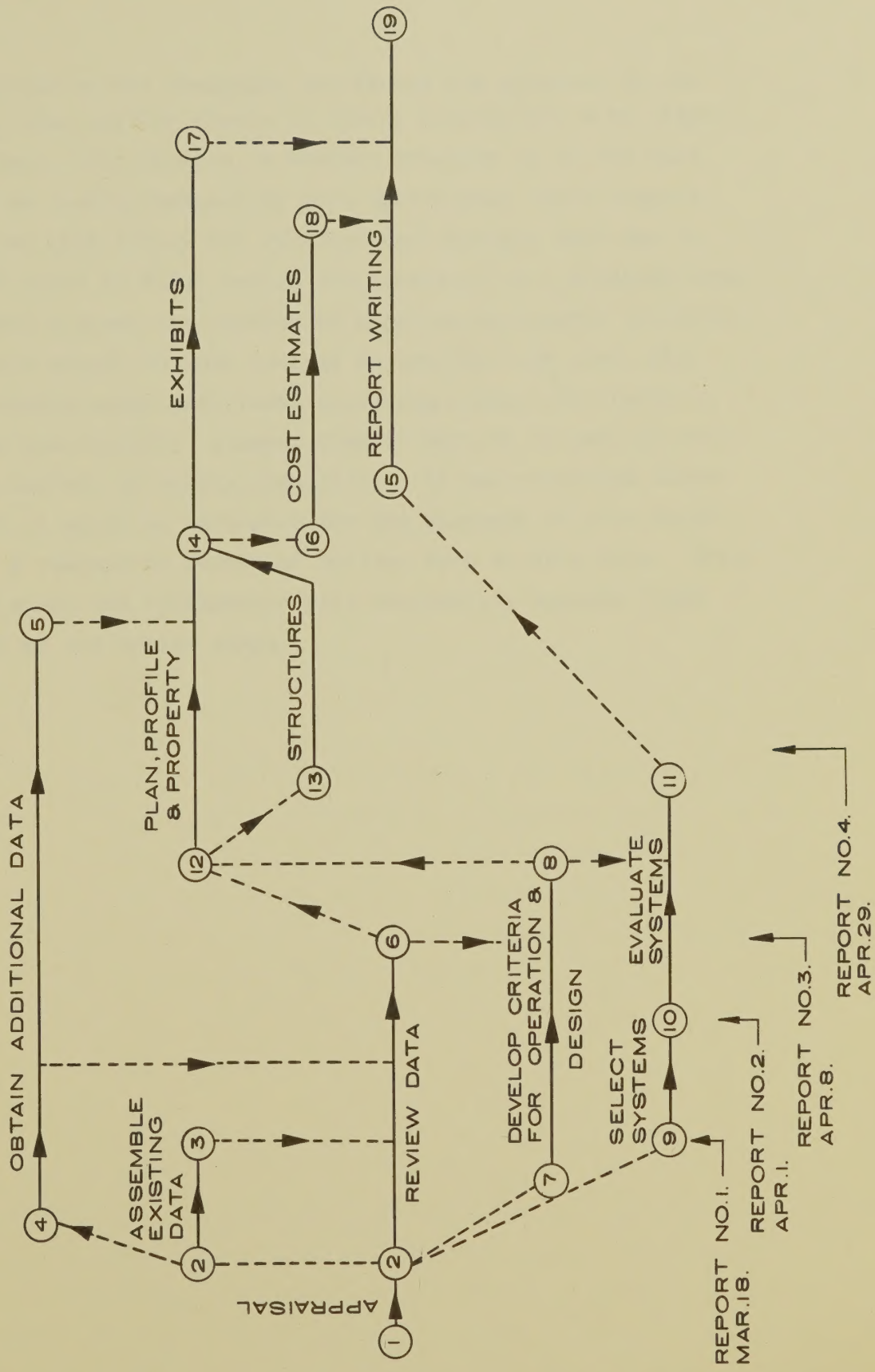
In addition to the meetings, the Consultants maintained liaison with the various Departments and Authorities and made field inspections, throughout the course of the Study, to obtain requisite data and information.

In the main, the Study comprised two interdependent parts:

1. The development of several preliminary alternative alignments in which it would be feasible to construct a rapid transit supporting way suited to the geophysical features, and
2. The selection and evaluation of rapid transit systems which would meet acceptable operational criteria and be suited to the alignments.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
MAR. 2	9	16	23	30	APR. 6	13	20	27	MAY. 4	11	18	25	JUN. 1	8	15	22

WEEK NO.
STARTING
DATE



HAMILTON AREA RAPID TRANSIT STUDY
WORK FLOW DIAGRAM

Consideration of the foregoing two facets was governed by the principle that neither should be overly restrictive with respect to the other. For example, a maximum gradient of 5% was used. This can be readily managed by most operational rapid transit systems and will likely not restrict new concepts that may be developed prior to final design and construction. Although some operational systems are capable of negotiating steeper gradients which would result in some savings in construction costs they would probably incur additional operating costs. Furthermore, gradients considerably steeper than 5% may not be satisfactory from the comfort or safety standpoint. It was concluded therefore that it would be advisable for the purposes of this Study to leave a reasonable number of options open at this time. More detailed study and refinements will necessarily precede final selection at the design stage.

SECTION 3

DATA ASSEMBLY AND REVIEW

The progress of the Study was expedited by the prompt receipt of all of the data requested from the various Departments and Authorities. Topographic plans, aerial photographs, utilities information, plans of current and proposed major constructions and soils information was included in the data that was furnished. In addition the following reports were received and reviewed for information relevant to the Study:

1. Report on Rapid Transit, dated August 1969 prepared by the Transit Planning Work Group.
2. Rapid Transit - Draft Official Plan 1970 of the City of Hamilton, prepared by the Planning Department.

At this time, the plans for Civic Square are still in the process of development. This precluded investigation of how the rapid transit station contemplated for that location could be integrated with that Complex. However it is anticipated that, should there be any conflict, both the plans for the Complex and the rapid transit could be modified without imposing serious constraints on either facility.

Utilities

Records of the type and sizes of all utilities within the areas influenced by the alternative rapid transit alignments were obtained from the City and the utility companies. The data was reviewed to ascertain how the utilities would affect, and be affected by, the proposed rapid transit lines. Meetings were held with the respective Owners and when unusual problems were encountered their advice was solicited regarding feasible solutions. In all instances, cooperation was received.

Where practicable the development of the alignments was governed by the desire to minimize conflict between the proposed structures and the existing utilities. For instance, there is a dense concentration of utilities under Burlington Street which favours elevated structure on an off-street alignment to avoid high costs of utilities relocation.

The services to all properties abutting the alignments would be maintained during construction either with temporary lines or by supporting existing lines in place.

Sewers

The gravity systems ranging from 6" dia. to 72" dia. are generally close to the centre of the road. Where necessary, the sewers would be reconstructed with concrete, vitrified clay or cement asbestos pipes. Smaller gravity systems that cross the line of construction would be flumed for a short duration until the sewer will be placed in the final position.

Major gravity system can be relocated before construction, where the position of the line and grade interferes with the construction. The sewer along MacNab Street, between Main Street and Cannon Street, varies from 54" dia. to 72" dia. and will require special attention during the design stage.

Water Mains

Varying sizes of water mains are encountered on different routes. The mains generally have 5 to 6 feet of cover. The mains can be supported in their present position in a sling type support during construction. Alignments ¹2 or ²3 would require relocation of a 30" dia. main crossing at Charlton Avenue and alignments 4, 5 or 6 would require relocation of a 36" dia. main crossing at Fennell Avenue.

Gas

The existing gas lines vary in size from 2" dia. to 20" dia. and from low pressure to high pressure. Lines are cast iron or welded steel pipes. Where exposure of these is necessary they would be relocated for the duration of construction and placed back to the original position during the backfilling of the excavation.

Telephone

The telephone service consists of overhead lines, underground cables and conduit banks. For the most part these would be supported in place during construction.

Hydro Electric

Similar to telephone plant, hydro electric plant would be supported in place during construction.

Soils

For the purpose of the Study, it was found necessary to supplement the soils data that was available from, and furnished by, the City Departments. On that account, Peto Associates Limited, soils consultants, were retained to prepare a soils report which is included in the Appendix.

SECTION 4

CRITERIA FOR OPERATIONS AND DESIGN

Interest in rapid transit has accelerated very significantly since the end of the Second World War so that currently scores of systems are under consideration. Prior to this accelerated interest, apart from the low capacity, low speed Wuppertal monorail, the only significant rapid transit systems in year-round service were operated with the conventional steel wheel vehicle on steel rail. This early conventional system has been improved over the years and, regardless of the development of new concepts, is still being adopted in most cases for initial rapid transit recently, or presently being, constructed in cities around the world, e.g., Toronto, Milan, Rotterdam, San Francisco, Washington, Caracas.

Of late, the most significant modification to the conventional rapid transit has been the trend toward rubber-tired trains, e.g., Montreal, Mexico City and the conversion of some lines in the Paris system.

A review was made of the forms of rapid transit currently in use and others in various stages of development which range from purely conceptual to prototype demonstration projects. It was concluded that operational and design data based on conventional rail rapid transit would serve the purposes of this Study.

It was considered that these criteria could be met by all concepts which are presently in operation, under development or likely to be developed. It was decided that the use of this criteria would leave a reasonable number of options open for future selection.

At this point it is emphasized that it should not be assumed that this concept is the one being recommended for Hamilton. It is highly likely that advances in rapid transit technology will present operational systems which are better suited to the Hamilton Area requirements.

In that event it is reasonable to expect that the criteria developed for this Study will not impose significant constraints on the design, construction, and operation of such systems. On the contrary, systems which may be adopted in lieu of that on which the Study criteria is based more probably will permit modifications to the criteria which will result in better operations and reduced first costs.

The following is the design and operational criteria used in the Study:

Vehicle width	10'-0"
Vehicle length	75'-0"
Vehicle height	12'-0"
Maximum length of train	300'
Maximum velocity	50 m.p.h.
Minimum velocity	30 m.p.h.
Acceleration	2.5 m.p.h.p.s.
Service braking	2.5 m.p.h.p.s.
Emergency braking	3 m.p.h.p.s.
Platform length	320'
Minimum tangent length beyond end of platform	100'
Minimum tangent length between simple curves	100'
Running track curvature - minimum radius	500'
Maximum superelevation (4'-8½" ga.)	4"
Gradients:	
Running line, maximum	5%
Structure, minimum	0.4%
Stations	0.4%
Vertical curve length	100 ($g_1 - g_2$)
Track centres	14'-0"

Clearance, centre line track to structure 7'-0"

Minimum clearance in circular tunnel structure 6"

Rail fastened to concrete on structure

Ballasted track on earthworks

SECTION 5

ALIGNMENTS

The development of alternative alignments was primarily directed at providing service between the four predominant areas defined in the Terms of Reference, i.e., the Mountain, the Escarpment, the Central Business and the Bay Front Industrial areas. Although the main concern was to determine the engineering feasibility of constructing a line that would connect the four areas, consideration was given to the general location of stations and the areas they would serve.

Approximately 20 different combinations of horizontal and vertical alignments were investigated. Several of the alternatives were eliminated following discussion and agreement with the Committee and finally, the remaining six that were considered to be viable were developed for the Study.

A matter of prime importance is the urgency to protect the requisite right-of-way i.e., to ensure against development along the proposed line that would result in more costly rapid transit construction.

The alternative alignments outlined in this Report are preliminary in nature. They have been developed to define the engineering feasibility of the lines in order to furnish guidance to the decision makers for their selection of the alignment to be adopted. It is emphasized that no recommendation is made in this Study with respect to the location, spacing or number of stations. These were assumed largely to determine physical engineering feasibility. In the final analysis the location of stations would be determined from a more detailed planning study.

The development of functional plans for the purposes of: locating the stations, outlining the alignment, establishing the structural forms, defining properties required for the right-of-way and preparing more

accurate estimates of cost, would follow the selection of the preferred general alignment. During the stage in which functional plans for a selected alignment are under preparation, the design criteria would be modified to take full advantage of the operational characteristics of the rapid transit vehicles suited to Hamilton area requirements. It is reasonable to expect that such modifications will result in criteria that will be less restrictive to the further development of the alignment with consequent benefit to the planning operational, environmental impact and economic aspects of the rapid transit system.

On the whole, the development of a rapid transit alignment along a corridor to connect the four main areas in Hamilton is a task that presents many difficult problems. If ever the question was posed as to whether it would not be easier to move a city and start all over again, it is one that could surely be asked in this instance. The natural and man-made obstacles related to the topography, geology, soils conditions and development are anything but insignificant in the development of vertical and horizontal alignments for a rapid transit along a north-south corridor connecting the four areas specified.

The Mountain Area

See Exhibits 3, 21, 22, 29, 30, 37, 38

In considering the alternatives on the Mountain, extensions southerly from Fennell Avenue are relatively easy. Regardless of whether the alignment is along Upper James or East 19th or a similar parallel nearby line, the alignment may be readily curved in the horizontal plane to serve desired centres. Also, it can be underground or elevated, and possibly even at-grade, with little or no restriction on line gradients. Planning, engineering, design, construction and operations may readily be handled by existing know-how and numerous options with respect to planned development would be available.

The development of alignments northerly from Fennell to connect the Mountain to the Central Area involves problems which impose significant constraints in view of the difference in elevation of 300 feet at the Escarpment. In order to maintain acceptable gradients without resorting to a lengthy circuitous route to overcome the difference in elevation between the Mountain and the Central Area levels, the choice is limited to an underground structure south of the Escarpment.

Regardless of whether the line is underground or elevated north of the Escarpment, the underground structure south of the Mountain brow would be of such depth that tunnelling would be the recommended method of construction. Generally, excavation down from the surface becomes uneconomical when the depth of cut is over 35 to 45 feet. Furthermore, according to available information, the characteristics of the rock and the conditions at the depths under consideration should present no unusual tunnelling problems. It is expected that it can be tunnelled at reasonable cost since during construction it will require only nominal support. Similarly the permanent lining need not be particularly substantial since it is anticipated that the rock will be largely self-supporting. The depth of the structure at Fennell will be governed by the selection of the alignment to the north.

From the viewpoints of engineering design and construction, there appear to be few constraints with respect to the alignment of the southerly extension. However, in analyzing this alignment relevant to desired development and centers to be served, due consideration should be given to the requirement for property on which to locate maintenance yards and shops for the rapid transit system. This is a matter that ranks high on the priority list in any deliberations since such facilities are essential to the initial operation of the system.

The line would rise as it proceeds southerly from Fennell and consequently, the depth at Fennell will govern where construction of the southerly extension will change from tunnelling to cut and cover. This will depend on the planning decisions with respect to the southerly alignment which in turn will fix the location at which the depth of sound rock and other soil conditions will dictate the change in the method of construction from tunnelling to cut and cover.

The depth of the most northerly station on the Mountain, (Fennell, Inverness or Mohawk) will be governed by its proximity to the brow, the attitude (elevated or underground) of the line north from the Escarpment, its east-west location (Upper James or East 19th) and the governing gradient. The drawings of the alternative alignments illustrate that there would be a considerable range of depths for this station and although all are feasible insofar as engineering and construction are concerned, the final location will be governed by an assessment of costs versus journey time and convenience. Journey time includes time spent: walking, on feeders, transferring, for vertical travel (escalators and stairs) and the train trip time.

All other things being equal, the further south of the brow that the most northerly station on the Mountain is located, the shallower the station may be. This would result in significant savings in construction and escalator costs. It would also decrease the time it takes to travel between surface and train level. On the other hand it is bound to have a detrimental effect on patronage that could be generated in the area north from the station to the brow. There is a natural tendency against back tracking on trips of relatively short length but quite probably the effect of this may not be significant. In fact, back tracking has been an accepted fact in the everyday life of Hamilton's motorists who negotiate the Escarpment through a series of switchbacks in the roads.

Finally, deep stations on the Mountain, in addition to being feasible from the engineering and construction standpoint, would be by no means unique. Several stations in the London Underground and in other cities around the world are considerably deeper than anything contemplated here.

The Escarpment Area

See Exhibits 4, 5, 22, 23, 30, 31, 38, 39

In discussing the rapid transit alignment in the Escarpment Area it is of little significance in the Study to define precisely the line of delineation between it and the Central Area. The transition is gradual and the Escarpment Area is treated as an integral part in consideration of the alignment for both the Mountain and Central Areas.

Regardless of whether the line is elevated or underground, it must traverse a zone of unstable soil after it passes the northerly face of sound rock. Following selection of an alignment in the Mountain formation, further investigation will be required to determine the extent and additional characteristics of the unstable soil zone which the line will traverse. The forthcoming data will be required for final design and will assist in the selection of a method of construction that will be both safe and economical.

Basically three alternatives are proposed for the area south of the T.H.& B. railway tracks. Alignments 1 and 2 are the same in this area and would be entirely in underground structure constructed by the cut and cover method. There could be a station in the vicinity of St. Joseph's Hospital at James and Herkimer.

Alignments 3 or 4 would emerge from the face of the Escarpment in the vicinity of St. Joseph's Drive and Ferguson and would be on elevated structure along Ferguson Avenue. An elevated station could be located in the vicinity of Forest and Ferguson.

Alignments 5 or 6 would be entirely in underground structure, cutting diagonally across to John and Young, and would then follow a line westerly, parallel to Augusta, to pass under James before curving to the North. An underground station could be located in the block bounded by John, Forest, Catharine and Young.

Soil conditions in the area south of the T.H.& B. tracks will present some difficulties during the construction stage for an underground line, but no special measures will be required with respect to the design of the permanent underground structure. Special techniques will be required during construction due to the high water table and the granular soils that will be encountered at the depths under consideration.

It is anticipated that the methods of construction will involve the use of conventional soldier piles and lagging combined with the slurry wall technique in carrying out the excavation. For excavation to expose and maintain underground utilities above the water table, soldier piles and lagging would be used. Below the water table, the slurry wall method would be used to retain the sides of the excavation to prevent loss of ground.

The problems posed by the soils conditions would be considerably reduced by resorting to an elevated instead of an underground line, and would much be preferred from a purely technical engineering point of view. However, from the standpoint of environmental impact it is an entirely different matter. It was concluded an elevated structure would be least disruptive with respect to visual intrusion and as a physical barrier if confined to a line in the vicinity of Ferguson. Therefore an elevated structure is proposed for the alternative alignments in the easterly area in order to take advantage of the economies that would be realized in construction costs.

Consideration of the other lines, 1, 2, 5 and 6, south of the T.H.& B. tracks led to the conclusion that elevated structures would be significantly disruptive and it was agreed that elevation for these alternatives should be eliminated for the present. However, if redevelopment will take place in the future, it may be planned so that an elevated structure would be acceptable in this area. In this event, the higher costs of underground construction in the difficult soils could be avoided.

The Central Area

See Exhibits 5,6,7,14,15,16,23,24,39,40,41

Two alternatives are proposed in the area north from the railway tracks to Cannon Street; one elevated and one underground. The continuation of Alternatives 3 and 4 would be elevated structure crossing over the T.H.& B. tracks and following the C.N.R. right-of-way northerly along Ferguson to Cannon and beyond. An elevated station would be located on these lines in the vicinity of King and Ferguson.

It is considered that an elevated structure along this line would be acceptable since it would not conflict with the present development. Furthermore, if redevelopment of the area is to be undertaken in the future it would be reasonable to expect that it would be planned and designed so that the elevated structure would be compatible with the new constructions.

Alignments 1, 2, 5 and 6 would be in underground structure tunnelled under the T.H.& B. tracks and would generally follow the line of MacNab Street. An underground station would be located between Main and King and possibly could be integrated into the Civic Square complex. At this writing the design of Civic Square is under development and definite information on it is not at hand for the purpose.

of investigating detailed location of the rapid transit facility. If an alignment is selected along this line, a station in the Civic Square undoubtedly would be of significant benefit to that complex and it is anticipated that the Owner would willingly cooperate by making provision in his design for the accommodation of a facility that would furnish rapid transit service.

However, at this time, the Civic Square designers have no authoritative information that would warrant making special provision in their design to accommodate future rapid transit. Similarly, until this Study is reviewed and decisions are handed down by the City it would not be reasonable to expect that the Developer should be approached to modify the design. On this account the Study Consultants have not contacted the Developers to furnish them with information relevant to future rapid transit.

As discussed previously, the boundary line between the Escarpment and Central areas cannot be firmly defined. The same holds true with respect to the line separating the Central Area from the Bay Front Industrial Area. Therefore, for the purposes of the Study it has been decided that the dividing line would be in the vicinity of the intersection of Victoria Avenue and Burlington Street.

Three alternatives are proposed for the continuation of the routes northerly from Cannon Street to the Bay Front Industrial Area. Alternatives 2 or 5 would be east of and parallel to MacNab. They would slope up to ground level in the block north of Barton and would continue to rise to elevated structure to cross over the C.N.R. tracks. At Macaulay the elevated structure would curve easterly to follow a line along the north side of Burlington Street to Victoria Avenue.

An underground station would be located in the vicinity of Cannon and elevated stations would be located on MacNab near Macaulay and on Burlington near Ferguson.

North from Cannon, Alternatives 3 or 4 would continue on elevated structure generally following the C.N.R. right-of-way along Ferguson, curving easterly to Wellington, northerly to Burlington and westerly along the north side of Burlington Street to Victoria Avenue. There would be two elevated stations; one at Ferguson and Barton and the other in the vicinity of Wellington and Macaulay.

North from Cannon, Alternative 1 or 6 would be a combination of the MacNab and the Ferguson lines. Continuing underground from the Civic Square station, northerly along MacNab the line would curve easterly along Cannon. It would then curve northerly, climbing to an elevated alignment in the C.N.R. right-of-way along Ferguson. There would be an underground station at Cannon and Hughson and two elevated stations on the Ferguson-Wellington line as previously described.

The appended soils report describes the varying geological formations and soils and groundwater conditions likely to be encountered along the alternative alignments proposed through this area. It may be concluded from the soils report that insofar as soils engineering factors are concerned, it is feasible to construct the types of structures in the attitudes and along the alignments proposed.

The Bay Front Industrial Area
See Exhibits 8, 9, 10

Along Burlington Street, easterly from Victoria Avenue, one alignment is proposed. It would be an elevated structure along a line that would be common to and a continuation of the six alternative alignments previously described. This alignment was developed to suit existing land occupancy conditions and roadways in addition to the presently planned Burlington Street improvement. For the most part, it will occupy privately owned property but will require the

demolition of a minimal number of buildings and the buildings to be demolished are considered to be neither substantial nor costly.

Much of the route could traverse those parts of the properties which have not been built upon and could also share land occupied by railway sidings. Existing structures along the line include H.E.P.C. transmission towers, overhead pedestrian and materials handling bridges and substantial buildings which would be costly to acquire or relocate. The elevated structure could be located to horizontally clear some of these and the others could be cleared vertically. Apart from the small land areas occupied by the piers and stations, most of the space above and below the elevated structure would be available for use of the land owners. East of Wellington there are five potential locations for the elevated stations in the following vicinities: Wentworth, Sherman, Gage, Ottawa and Kenilworth.

Soils conditions favour an elevated rather than an underground structure. It is possible to construct an underground line through this area but in view of the high costs associated with the soils condition problems, it would not be a feasible solution. Furthermore, in this industrial environment an elevated structure would cause little disturbance and would be acceptable.

SECTION 6

EXTENSION STATIONS AND ACCESS

Rapid transit extensions, branches and connections to the alternative alignments investigated within the limits of this Study would be determined in the Feasibility Planning stage, as described under "Course of Future Action", Section 1.

No serious problems are apparent with respect to extending the alternative alignments southerly from Fennell and easterly from Kenilworth. A branch line connection off the Burlington Street elevated structure to run northerly across the Harbour could also be made.

The extension southerly from Fennell could gradually climb to elevated structure, depending on planning and environmental acceptability of the areas to be traversed by the extension. Future east-west rapid transit lines could also be constructed along Fennell or Mohawk. The service could be integrated by providing for transferring between the east-west and the north-south lines at stations on the Upper James or East 19th alignments.

The construction of an east-west rapid transit line on the Mountain, if and when warranted, would follow construction of the north-south lines probably after a time interval of several years. In the meantime, east-west service would be by surface transit and convenient bus to rapid transit transfer facilities could be provided at the rapid transit stations.

The alignment of the elevated structure easterly from Kenilworth, to be determined in the Feasibility Planning stage, among other alternatives, could be extended in the future northerly across the Harbour to serve the Burlington Area. Alternatively it could be extended south-easterly or it could be branched to incorporate both schemes.

There are possibilities for a connection between a future east-west line in the Lower City through the Central Business District and the north-south line. Although it is anticipated that these would present some difficult problems, and entail more costly construction due to the soil conditions at the depths contemplated; it appears that a physically feasible solution could be developed.

Station platform lengths were assumed to be 320 feet, in the development of the alternative alignments. In the final analysis, these could be reduced, or slightly increased, to accommodate trains of various consist e.g., up to two married pairs of 75 ft. cars or three married pairs of 55 ft. cars for maximum train lengths of 300 feet and 330 feet respectively. Station lengths and locations are matters of prime importance and would be established in the Functional Planning stage.

Location of station, as assumed for the purposes of this Study, could provide ready access to surface feeder bus lines. This is essential to the optimum utilization of a rapid transit system.

Bus to rapid transit transferring facilities, for development in the Functional Planning stage, should be designed for projected peak volumes at individual stations with due consideration to passenger convenience and vehicle movements. The layout of these facilities should be directed at minimizing conflict between buses and other traffic, in the interests of safety and reducing journey times.

In considering access between the surface and deep stations, the most critical cases occur with alternative alignments 1 and 2. The depth down to train level in a station at Fennell and Upper James would be approximately 125 feet. The single rise for an escalator here could be 90 feet, by constructing the ticketing level 30 feet below grade.

Although feasible, the desirability of an escalator of such height is questionable. This could be overcome by splitting the rise with an intermediate level so that maximum escalator height would be approximately 50 feet, which would be acceptable.

The depth to train level at a station on alternative alignments 5 and 6 at Inverness and East 19th, would be approximately 80 feet. This could be split into two escalator rises; one, 30 feet down to ticketing level and the other, 50 feet down from ticketing to train level.

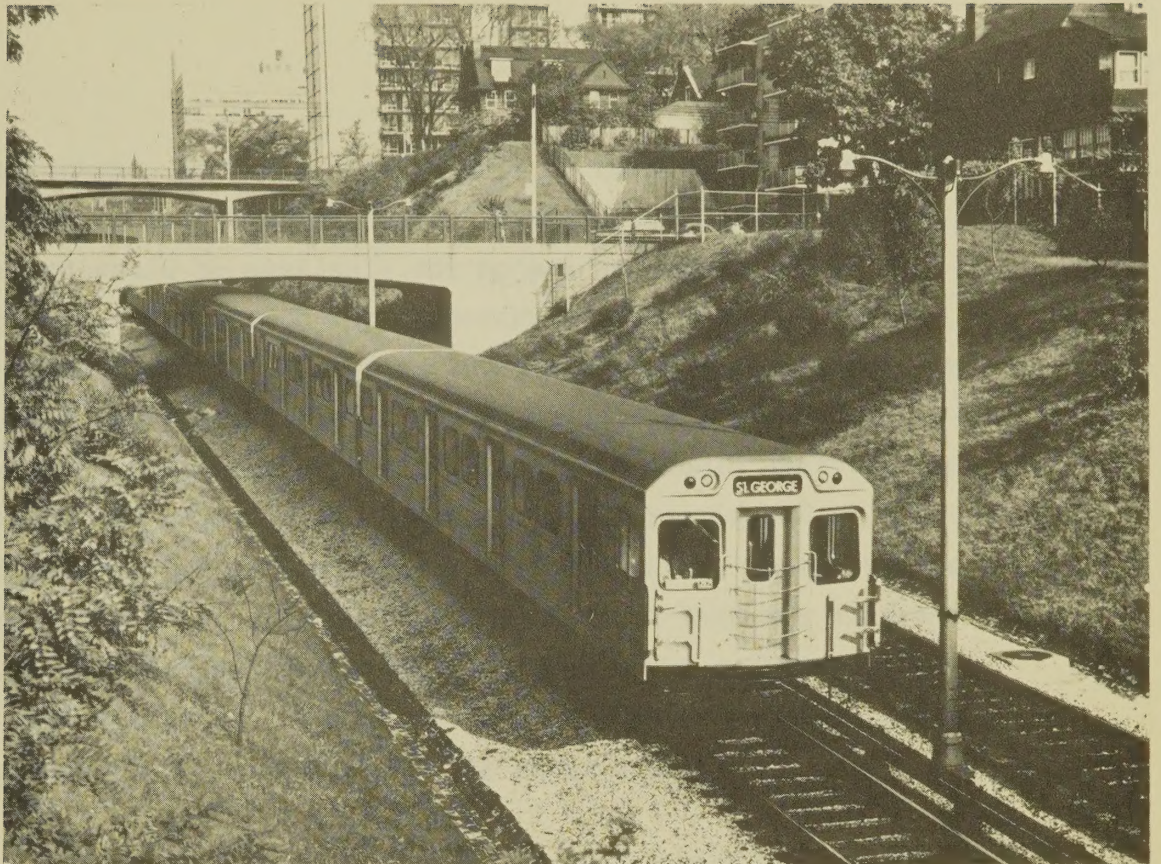
SECTION 8

STRUCTURES

Reference is made to Exhibit ⁵⁴ A for illustrations of typical rapid transit structures. The running section (between stations) will generally be either tunnelled structure, cut and cover structure, or elevated structure. The tunnel section shown is based on a mining process of construction in which the rock is drilled, blasted and removed. The rock cavity thus excavated is lined with reinforced concrete which may be placed by a forming and pumping process or by a sprayed-on application technique. The semi-circular tunnel section provides for 13 ft.0 in. track centers with a 2 ft.0 in. catwalk against each wall. The radius of curvature of the roof would conform to the arching characteristics of the rock and would provide clearance for the dynamic outline of the vehicle.

The tunnelling technique contemplated in this Study is based on a conservative method and assumes the employment of the mining process of excavation and the forming and pumping method of concrete lining placement. The possibility of utilizing a rock boring machine, which could result in economies, would be investigated in the functional planning stage. It would produce a tunnel of circular cross section. Other alternatives would also be investigated in the functional planning and design stages.

The cut and cover section is a reinforced concrete two-cell rigid frame structure. Catwalk facilities similar to the tunnel section, are provided. Additional refuge areas are furnished by the regularly spaced openings in the center wall. The center wall openings also permit access between the tracks. The cut and cover method of construction involves the driving of soldier piles on both sides of the proposed structure, followed by first lift excavation and timber lagging between soldier piles. During this first lift of excavation, the utilities near the surface utilities which are to be maintained



RAPID TRANSIT IN LANDSCAPED CUTTING TORONTO



SAN FRANCISCO ELEVATED STRUCTURE

in place (telephone, electric, etc.) would be temporarily supported after exposure. Street decking, where required, would be installed and the surface would be available for normal operations while excavation continues underneath the temporary street decking. After completion of excavation, the reinforced concrete structure would be built, the area above backfilled, soldier piles withdrawn and utilities and pavement would be restored. This method would apply to the sections of cut and cover on the Mountain in Alternatives 3 to 6 inclusive. Cut and cover sections north of the Mountain would involve a variation in the above construction procedure in that the excavation would be retained by the method described above combined with the slurry wall technique. This combination would be required where the structure is to be located below the water table.

The elevated structure comprises a cast-in-place continuous post tensioned concrete superstructure carried on single legged piers of reinforced concrete. The foundation supports would be concrete filled steel cylinder piles. While the Burlington Street area would require these piles to be driven to depths ranging from 80 to 100 feet below grade, improved foundation conditions are encountered for the elevated structure in areas south of Burlington Street where concrete piles, driven to approximately 50 or 60 feet below grade, would be adequate. Foundation and pier construction would follow the normal methods of construction. Superstructure construction for the cast-in-place method consists of placing the concrete in forms supported by falsework and after an appropriate time lapse, applying tension to the stressing elements. The stressing elements are placed in the formwork along with reinforcing bars prior to the placing of the concrete. Variations of this method are available, e.g., the "segmental" method, in which sections of the superstructure, of manageable size and weight, are precast and lifted into place. Stressing elements are threaded through preformed holes in the precast sections and tensioning is applied.

Miscellaneous structures such as ventilation shafts, pumping stations, crossover track sections, transition structures, etc., would in general conform to the construction methods described above, but would be specially designed appropriate to their particular functions.

Station structures would be constructed in a manner similar to that of running track sections. These would be widened to accommodate platforms. Underground control areas would be located as near to ground level as possible and as such would be cut and cover type structures. Other control areas could be constructed at ground level for stations on the elevated portions of the line and in special circumstances for underground stations.

SECTION 9

COSTS

The cost estimates summarized in Section 1 of this Report are based on the limited subsurface information available and on the potential number of stations indicated for each alternative alignment. Elevated structure spans of 80 to 100 feet have been assumed.

Rock tunnel cost will vary according to specific location and depth in the Escarpment and will further vary near each end as special conditions at these points will require special treatment.

Cut and cover construction where ground water problems are assumed to be nominal such as on top of the Mountain for Alternatives 3 to 6 inclusive would be less costly than the areas below the Mountain where the high water table would require use of the slurry wall technique for excavation protection.

Elevated structure cost would vary with pier height, foundation conditions, and any non optimum span lengths required due to physical requirements such as an existing building which must be spanned or where a specific clear space under the structure is required for particular purposes.

Station costs vary with the types of station contemplated, (cut and cover, tunnel, elevated); surface access requirements; depth below or height above ground; and control area requirements.

Following are the average estimated costs for the above described items, including an allowance for engineering and contingencies:

Rock Tunnel	\$ 2,300 per lin. ft.
Cut and Cover (Nominal ground water)	\$ 2,300 " " "
Cut and Cover (High water table)	\$ 2,900 " " "
Elevated Structure	\$ 950 " " "
Underground Stations	\$2,900,000 per station
Elevated Stations	\$2,000,000 " "

Note: Station costs include escalators, fare collection equipment, and architectural finish.

The cost estimates for "Utilities" represents the cost of maintaining, restoring, and relocating (in some instances), the following services:

Water Mains
Gas Mains
Sewers
Hydro Electric
Bell Telephone

APPENDICES

APPENDIX 'A' TERMS OF REFERENCE

APPENDIX 'B' RAPID TRANSIT SYSTEMS

APPENDIX 'C' SOILS REPORT

APPENDIX A

REPORT OF THE COMMISSION FOR A COMPREHENSIVE RECONSTRUCTION OF THE CITY OF NEW YORK IN THE DISTRICT OF COLUMBIA, THE CITY

RECOMMENDATIONS

The Commission and the Planning Board have sought a solution to the problems of the city.

APPENDIX 'A'

The Commission has in this report made the City of New York
the most important of the problems of the City. In order to
the Commission has

TERMS OF REFERENCE

The Commission has sought to make the City of New York
the most important of the problems of the City. In order to
the Commission has

The Commission has sought to make the City of New York
the most important of the problems of the City. In order to
the Commission has

The Commission has sought to make the City of New York
the most important of the problems of the City. In order to
the Commission has

However, it is important that the City of New York be not
overlooked and that the Commission be not overlooked. The
Commission has sought to make the City of New York
the most important of the problems of the City. In order to
the Commission has

APPENDIX A

TERMS OF REFERENCE FOR A PRELIMINARY ENGINEERING REPORT ON RAPID TRANSIT IN THE HAMILTON METROPOLITAN AREA

Background

In February 1969 the Hamilton Transit Commission sought a solution to two existing and continuing problems:

- (a) the necessity to be able to get people from the Lower Level to the Upper Level of the Mountain at all times, in spite of icy roads and blocked access routes;
- (b) an effective plan which will remove or, at least, alleviate car parking in the North End Industrial Area.

An Outline Plan for Rapid Transit was submitted and, after due consideration, the Commission suggested to the City that a Feasibility Study be undertaken jointly with the Ontario Department of Highways.

The Board of Control appointed a Committee of three, to be known as "The Hamilton Transit Planning Committee", to advise the Board if such a Study should be undertaken. The Committee set up a Work Group to ascertain the relative facts and, subsequently, reported that a full scale Feasibility Study would be premature at this time.

However, it developed that the H.A.T.S. Plan is now outdated and much material and information contained therein has been changed. The Planning Commissioner for the City of Hamilton is currently undertaking a Study and gathering material for the Official Plan for the City, which will be ready for preparation by August 1970. It becomes essential to the Planning Commissioner to know at an early date if Rapid Transit in any form is both feasible and practical for the City before he starts his initial layout. To this end, the Hamilton Transit Commission, in conjunction with the City of Hamilton, will undertake a limited Geophysical Study to ascertain if Rapid Transit is both practical and

possible for Hamilton, and, if so, the general form in which the development should take place with approximate costs relevant thereto. The Study would be carried out by a firm of Consulting Engineers in accordance with the Terms of Reference outlined herein.

Objective

The main objective of the Study is to obtain information upon which policy decisions may be made with respect to the reservation and protection of the possible corridor, or corridors, for the future construction of a rapid transit facility in Hamilton, with particular reference to the Central Business District.

Major Considerations

- (a) To investigate and report on the geophysical problems and constraints relevant to the provision of rapid transit service in the corridor with due regard to the inherent problem of "Mountain" access.
- (b) To develop preliminary alternative horizontal and vertical alignments for a rapid transit facility required to serve the corridor and to identify the significant features involved in the reservation and protection of the alternative alignments.
- (c) To investigate various types of rapid transit which might offer a solution to the problems and constraints relevant to (a) above, which could operate over the alternative alignments developed in (b) above and to evaluate each type, firstly, on the basis of its relative physical feasibility, and secondly, on a cost comparative basis.

Factors to be Considered

Generally, there are four main areas which characteristically differ along the proposed north-south study axis in the Hamilton Area.

These are the Mountain Area, the Escarpment Area, the Central Area (including Downtown) and the Bay Front Industrial Area. The investigation of the alternative alignments and concepts shall consider their relationship to the following factors in these areas:

1. Mountain Area

- (a) Difficulties (added costs) of simultaneous curvature and gradient-maintenance in deep tunnel(s).
- (b) Provision for future extension southerly.
- (c) Access between surface and deep stations.

2. Escarpment Area

- (a) Shortest distance, minimum time, in gaining access to Mountain Brow.
- (b) Relative costs of a single or twin tunnels, straight or curved, etc.
- (c) Comparative profiles.
- (d) Environmental impact.

3. Central Area (including Downtown)

- (a) Effect on environment.
- (b) Provision for future rapid transit lines.
- (c) Connection with other modes.

4. Bay Front Industrial Area

- (a) Availability of railway networks.
- (b) Possible easements or air rights over industrial land holdings.
- (c) Provision for future extension.

General Conditions

- A) The Consultants shall work under the general supervision of, and submit periodic progress reports to the Hamilton Transit Commission, the City of Hamilton Transit Planning Committee and to the representatives of the Ontario Department of Highways.
- B) The warrants for the feasibility of implementing rapid transit service are not to be investigated by the Consultant. These, i.e., passenger volume, operational and maintenance costs, revenues, financing, implementations, etc. would be analysed in the future.
- C) Recommendations on Escarpment alignments shall be presented in general terms only, and only if significant differences in cost are likely to result between such alternative general alignments.
- D) Report, in general terms, on land requirements for the corridor and systems under review, including: land required for stations and structures, turning radii, switching facilities, gradients, etc., as well as problems involving surface access from deep or elevated stations.
- E) Alternative rapid transit concepts shall be investigated generally to determine the most suitable type, or combination of types, of rapid transit which may be suitable for the corridor. The development of operational networks will not be attempted for any of the concepts.

- F) The alternative rapid transit concepts to be considered in general shall include the following:
- i. Conventional rail rapid transit
 - ii. Westinghouse Transit Expressway
 - iii. Tracked air cushion vehicles
 - iv. Bus rapid transit
 - v. Monorails
- G) Comparative construction costs shall be determined for each alternative alignment and rapid transit concept. All costs shall be calculated on a 1970 dollar basis.

Services Required of the Consultant

The Consultant shall meet all the above stated conditions in fulfillment of the Study objectives. In so doing, the evaluation of each alternative, on the basis of its relative feasibility with regard to the geophysical determinants, shall include:

1. A report on soil types, depth of bedrock, and water table levels, as these may relate to engineering design, construction methods, bearing loads, finishing requirements, etc. which ultimately affect cost.
2. A report on the types and general locations of existing and proposed major utilities, structures and developments as they may affect or be affected by the implementation and construction of the alternative rapid transit system.
3. A report on the adaptability of the existing rights-of-way to the alternative alignments and rapid transit concepts.

Information to be Furnished to the Consultant

As required, the City of Hamilton shall provide the Consultant with the following information, if available, from the various City Departments and Authorities:

1. Aerial photographs
2. Base maps
3. Underground and overhead utilities
4. Soils data and reports
5. Foundation conditions of existing and proposed structures
6. Plans of proposed development
7. Plans of current and proposed major constructions

It is understood that the Consultant will not be required to undertake field topographic surveys, field sub-surface investigations or field soils explorations.

The Client will cooperate in obtaining for the Consultant as much of the above information requisite to the conduct of the Study as may be available. It is anticipated that sufficient data of this nature will be available for the purposes of this Study. However, if it is essential for the Study, the Consultant would be compensated for a limited amount of field survey and investigation which would be undertaken following approval by the Client.

Progress and Completion

The Consultant shall commence work within two weeks following notification of authorization to proceed.

During the course of the assignment the Consultant shall furnish the Committee and the representatives of the Ontario Department of Highways with ten (10) copies each of a progress report at the end of each of the below listed phases, outlining the work that has been completed to date and the schedule of work to be undertaken to completion. It is to be understood that there also shall be oral presentation made to the principals at the completion of each phase.

- Phase 1 - Review of immediately available data
- 2 - Selection of systems to be analyzed
- 3 - Review of finally assembled data
- 4 - Selection of alternative alignments
- 5 - Final Draft Report

Within four months following the commencement date for the work, the Consultant shall furnish the Client with a final draft of completed report, ready for printing.

APPENDIX 'B'

RAPID TRANSIT SYSTEMS

APPENDIX B

RAPID TRANSIT SYSTEMS

1. Rail Rapid Transit

Rail Rapid Transit is the most common form of rapid transit. It suffers from an old fashioned image accentuated by the quantity of vintage rolling stock that still rattles around in many cities. However, in an extensive array of detailed studies from San Francisco to Rotterdam to Hong Kong its superiority over all other concepts for serving high density passenger volumes has been repeatedly validated. To avoid this old image the term Duorail is frequently used.

Duorail is derived from railroad development and uses on a variety of gauges. Toronto for example is a non standard 4'10½" while the new BART system in San Francisco has chosen a wide 5'-6" gauge to improve high-speed stability. It is anticipated that 4'-8½", standard railroad gauge, would be suitable for the urban type of system required in Hamilton. Duorail track can be mounted directly on concrete for tunnel and elevated sections utilizing resilient pads to reduce noise and vibration, elsewhere continuous welded rail on wood or concrete tie provides the advantage of low cost and ease of maintenance and alignment. The track serves both as support and guidance and has the significant advantage of using readily available components. Switching is easily accomplished as distinct from the other systems where complicated switches are a considerable disadvantage.

From the track up, Duorail systems encompass a wide variety of equipment that can be designed to meet almost any requirement. The size of cars can range from 40 to 75 feet long and 8 to 11 feet wide. Propulsion is generally provided by parallel drive DC motors with their ideal torque-speed characteristics, more than adequate power for Hamilton's grades can be provided.

In the past decade considerable development has taken place in control and signalling equipment. The application of power to the motors can be handled smoothly with modern thyristor chopper control or the less sophisticated but cheaper cam-control. Braking blends dynamic electric brake with air brakes operating on either the wheel treads or on disk brakes. The steep grades in Hamilton suggest that some form of regenerative braking should be considered, particularly as this reduces heating in tunnel sections as well as reducing power consumption - at the penalty of increased capital and maintenance costs.

Signalling can be provided in differing levels of sophistication ranging from total automatic train control by a central computer to conventional track circuit signalling with cab signals and automatic stop protection.

Passenger accommodations are not dependent on the system. Lighting, seating, air conditioning, public address systems can be installed to whatever level of luxury can be afforded.

2(a) Metro

The concept of using rubber tires on a guided vehicle was unsuccessfully attempted by the French National Railways in the thirties. The load limitation imposed by the tires running on the narrow steel rail was severe and the multi-axle trucks complex. In 1961, the Regie Autonome des Transports Parisiens (RATP) experimented with rubber tires by fitting a transit car with truck tires running on boards outside the rails and guided by horizontal wheels running against vertical boards on either side of the track. The experiments were declared successful, and lightly loaded Line 11 was converted, going into operation in 1957. Following this, the heavy Line 1 was converted in 1963. Passenger complaints about the high accelerations on this line caused it to be reduced and RATP appears to have lost enthusiasm for the rubber tired Metro. Plans for conversion of more of the Paris Metro were postponed.

The City of Montreal has opened three subway lines using the RATP rubber tire system and this system has also been used in Mexico City. The Montreal vehicles are described below.

Each motor and trailer car has two trucks. Four Michelin steel cord pneumatic tires per truck (about the size of a 12 x 16 tire) provide traction, backed up by an auxiliary flanged steel safety wheel mounted on the same hub. The steel wheel acts primarily as a brake drum but also provides lateral guidance through switches. Lateral guidance normally is provided by pneumatic rubber tires mounted on a vertical axis at both ends of each side of each truck. These tires ride against inverted "L"-shaped steel rails which also are used to transmit traction power to the cars. Should one of the horizontal or vertical pneumatic tires go flat, the resultant movement of the car would bring the steel safety wheel into contact with the steel rail directly below. In normal operation the steel wheels will not ride the rails, although their flanges extend down far enough to take over guidance if a tire deflates.

The three-car units can be operated individually or in trains of two or three units, thus permitting the operation of three, six, or nine-car trains. A three-unit (nine-car) train is 500 feet long. The physical characteristics of the trailers are basically the same as the motor cars, except for the absence of the operator's cab and propulsion and control equipment.

The basic concept of the Metro car, as mentioned above, was taken from the Paris Metro. Whereas the rubber tired rolling stock used in Paris had to be designed to meet the existing clearances of Metro lines which have seen decades of use with conventional steel-wheeled equipment, the Montreal Metro cars were designed for a brand new facility. The result is a slightly larger, more luxurious design, blending North American and European features.

Propulsion for each motor car is provided by four DC self-ventilated 155 horsepower motors mounted parallel to the car axis (right angle drive) which can achieve 4,000 rpm with a minimum of noise. Power is transmitted to the driving wheels through double reduction differential units. A series-parallel control is used, but the two motors on each truck are connected permanently in series.

All braking is mechanical through oil-impregnated wooden brake shoes acting on the treads of the operating steel safety wheels. The shoes are activated by truck-mounted compressed air cylinders governed by an electric brake control. Dynamic braking, found on all other modern North American rapid transit cars, but not used in Paris, is not included in the design.

Carbon pickup shoes extend outward to meet the lateral guide rails, which deliver power to the trains. Negative return and grounding is accomplished by cast iron shoes extending below the trucks and sliding on the standard steel rails.

There are four double doors on each side of the cars. Forty seats, arranged in a transverse and longitudinal pattern are located in a manner designed to make the doors readily accessible to all passengers. The large number of doors in relation to car length (36 doors for a 500-foot long, nine-car train with a capacity of approximately 1,440 passengers) has reduced station stop time for loading and unloading to a minimum.

A train-to-wayside telephone system provides communications between operators and the Metro control center, between the two operators on each train, and between the operators and passengers (via the on-train public address system).

Discussion

Although the vehicles for the Montreal system were expensive, the tunnels were constructed very economically, helped by the vehicle's narrow cross section and its grade climbing ability. This permitted the tunnels between stations to dive to a depth that maintained construction in solid rock and avoided utility relocation. Some 70% of the total mileage was built this way. The characteristic 4% upgrade entering and downgrade leaving most stations also assists braking and acceleration. This detail is really the only way in which Montreal is using the increased flexibility that its rubber tired system provides. Even so, such grades could be negotiated by conventional rail equipment in the controlled environment of a subway.

The resistance control and all-wooden shoe braking has created, with the help of the rubber tires, an immense problem of excess heat. Also on the negative side is the bouncy ride quality, and a higher than necessary noise level due to the narrow tunnels, acoustically hard stations, and a general lack of noise control in the design. It should be noted that except for the ride qualities, none of these problems are necessarily inherent in the Metro system.

2(b) Westinghouse Transit Expressway

Transit Expressway is a concept developed by the Westinghouse Electric Corporation to provide a lower cost automatic transit system capable of handling moderate passenger volumes. The system was designed and built in 1964 as a demonstration project of the U.S. Department of Housing and Urban Development and the Port Authority of Allegheny County, in South Park, Pittsburgh.

The Transit Expressway concept involves the operation of all electric, minimum weight, single or multiple vehicle trains, on all-

exclusive right-of-way, in either an elevated, at-grade, or subway mode as dictated by environmental and economic considerations. System, vehicle, and train operations are automatically controlled, with no operator or attendant on trains.

The running surface or "track slabs" are 22-inch wide, 5-inch thick ribbons of reinforced concrete poured on top of steel I-beam girders supported by the columns. The concrete is locked to the top flange of the girder by shear connectors so that it acts compositely with the girders in carrying the imposed loads.

Vehicle

Design of the vehicles for the Transit Expressway was predicated on a desire to use "automotive practices" where possible. To achieve low capital and operating costs, design considerations required a minimum-weight vehicle that was fully automatic in every respect with no on-board operator.

The 30.5-foot long, 8.67-foot wide, self-propelled unit will accommodate 28 seated passengers and 42 standees as an optimum rush-hour load. Production vehicles are expected to be slightly larger. All-season air conditioning is provided. The vehicle suspension, electric motor propulsion, braking system, and pneumatic rubber tired wheels, in combination with closely held tolerances of the roadway, provide a smooth, silent ride.

The vehicle runs on four driven wheels with dual pneumatic rubber tires. Both the forward and rear axles are steered. Four pneumatic rubber tired guide wheels, carried on frames fastened to each axle, grip the steel "I" guide beam. A steel disk mounted immediately above each guide wheel serves to prevent bottoming out of the guide tire, and to lock the vehicle on the roadway in event of excessive overturning forces.

All vehicle sprung mass is carried on air bags and coil springs. The air bag system also gives automatic leveling in loading and on curves. Shock absorbers are installed to snub vertical and lateral motions.

Each vehicle has a coupling device so that it may be coupled into a train in any position. Ten or more vehicles can be operated in a train. Both mechanical and electrical circuitry coupling is achieved. The coupler is fully automatic in operation.

Propulsion

Two 100 horsepower direct current electric traction motors provide the propulsion for each vehicle. Each motor drives an axle through a drive shaft and differential. Silicon controlled rectifiers (thyristors) connected in a three-phase bridge configuration give smooth stepless control of power to each drive motor. Braking is a two-step process. Braking forces are obtained by reversing the fields of the driving motors, giving dynamic electrical braking. As the forward speed of the train decreases and the dynamic braking fades, air brakes become effective and bring the train to a complete stop. The South Park installation used an experimental three-phase A.C. power supply but conventional D.C. third rail power is proposed for operating systems.

Discussion

The Transit Expressway system was designed and built with over five million dollars of U.S. federal, local government, and industry funds, and so represents one of the more comprehensive attempts to engineer a complete transit system.

Particularly in the areas of solid state propulsion and braking control, computer controlled automatic train operation, and three-phase power collection the project has been outstandingly successful. It has produced sophisticated equipment that is not only applicable to Transit Expressway but can be adapted to almost all types of transit vehicle.

In designing a transit vehicle there are a large number of items that have to be incorporated in every vehicle - at least two axles, motors, controls, brakes, air conditioners, lights, heaters, power doors, automatic train controls, couplers, air compressors, switch-gear, power collectors. Much of the cost and weight of these is independent of the vehicle size and consequently the general tendency is to build as large a car as possible. Transit Expressway, aiming at filling the gap between buses and heavy rapid transit, uses a vehicle that is half the size of a heavy transit but probably without commensurate savings in cost.

On the negative side, Transit Expressway uses a rigid central guidance system that requires both a guide beam that is expensive to install and maintain in alignment and a switch that is complex, and costly as compared to that for rail type systems.

3. Monorails

Monorail systems have been proposed for urban transportation for many years. Generally under-engineered and over-promoted, they have found application mostly in amusement parks and exhibitions. Proposals have been developed as early as the Palmer system in 1880. The modern Alweg and Safege systems are discussed herein.

While not strictly monorails in the sense of having a single set of wheels on a single rail, the latter two systems represent the two distinct classes of monorails. Alweg is an overriding monorail; Safege is a suspended monorail.

3(a) Alweg System

The Alweg system was developed in Germany in the early fifties at the instigation of the Swedish industrialist, Dr. Axel-Lennart Wenner-Gren. A test track was built at Cologne Fuhlingen, followed by a 5/8 scale line at Disneyland in California in 1959, and short lines at the Italia 61 Fair in Turin, Italy 1961, the Seattle World's Fair, 1962, and several locations in Japan. The first full scale operation was the 9-mile line linking Tokyo with its international airport at Haneda, placed in operation in 1964. This line has failed to give either a smooth or fast ride and initially attracted little patronage from the parallelling expressway; however as this latter facility has become increasingly congested, patronage on the monorail has increased.

A narrow beam of rectangular cross section, supported by pylons, serves both as permanent way and supporting structure. It constitutes a continuous bridge sited over the street level traffic in order not to obstruct it.

The undercarriage of the Alweg car straddles the beam in such a way that the rubber tires of the supporting wheels run on the top surface of the beam, while the guiding and stabilizing wheels, which are likewise equipped with rubber tires, contact both lateral surfaces of the beam. This arrangement permits high speeds with minimum running noise and offers security against derailment. Trains can be formed by coupling several units together.

Two different types of switches have been developed: a flexible switch for normal operation, consisting of light metal hollow beam sections, which is bent in its entirety into the branch-off position and has a switching time of approximately 10 seconds; and an articulated switch as a shunting switch for use in depots and maintenance shops, consisting of movable jointed beam sections which, in the shifted position, form a polygon. Both systems can be designed for use as a multiple switch.

Vehicles

The vehicles are designed as two, three, or four-car units that can be coupled together to form trains. Each car has a passenger capacity of approximately 100 persons. The ratio between seating capacity and standing room depends on the specific design of passenger compartments.

The car bodies are of self-supporting light-weight structure with two undercarriages, the wheels of which straddle the beam track with their rubber tires. There are two vertical supporting wheels for weight, drive, and brakes and four horizontal guiding and stabilizing wheels to absorb lateral forces.

Air suspension of the supporting wheels provides automatic leveling of the car floor. Propulsion is provided by a conventional D.C. traction motor and control from a two-rail collector (one positive and one return rail). Dynamic and air actuated disk brakes are used.

Discussion

In the design of a transit vehicle, the wider the gauge the more stable the system. Unfortunately economics have prohibited development in this direction, particularly for elevated systems where a wide guideway would be both expensive and visually unacceptable. The Alweg system effectively takes a wide gauge car and wraps it around a rectangular beam, providing stability with a minimum of visual obtrusion by the guideway. This is the main asset of the Alweg system.

The clamping of the vehicle to the track provides a ride quality dependent on the precise alignment of the structure and the systems built to date have been unsuccessful in providing a smooth ride.

The vehicle configuration has the trucks protruding into the passenger space, hindering interior design and restricting passenger flow, while still requiring an abnormally high vehicle with consequently, costlier tunnels. Cornering requires superelevation built into the track and such superelevation is limited by exactly the same criterion of passenger comfort as a conventionally supported vehicle. Thus the Alweg system introduced most of the disadvantages of the Safege system with few of the advantages.

3(b) Safege Monorail

The Safege monorail is an underhanding system, developed in France on a one mile test track at Chateauneuf-sur-Loire, south of Paris.

Structure

Safege is not strictly a monorail, as it utilizes trucks, very similar to those of the Paris Metro, running on two tracks. These two-wheel tracks are continued in a hollow prestressed concrete beam approximately seven feet wide and six feet deep, supported at intervals of about 100 feet. Longer spans utilize a steel box beam or a prestressed steel box beam; curved beams are generally supported at more frequent intervals.

Vehicles

Each vehicle is suspended from two Metro-type trucks, propelled by four D.C. motors each of nominal horsepower ranging from 75 to 140. The traction control and automatic train control (ATC) on the Safege prototype are not technically notable, but again it should be pointed out that modern developments in solid state controls and computerized ATC are equally applicable to all the fixed guideway systems in this

report. Below the beamway, the vehicle is free from constraints on size and shape and can be built to meet any operating requirements as long as it remains within weight limits. The most important aspect of the Safege system is the suspension. This cushions the vehicle from truck motion and noise. It permits the vehicle to incline while negotiating a curve. The suspension uses a linkage system with pneumatic dampers and pneumatic bellows. A high-tensile steel safety cable supports the body in the event of a suspension failure.

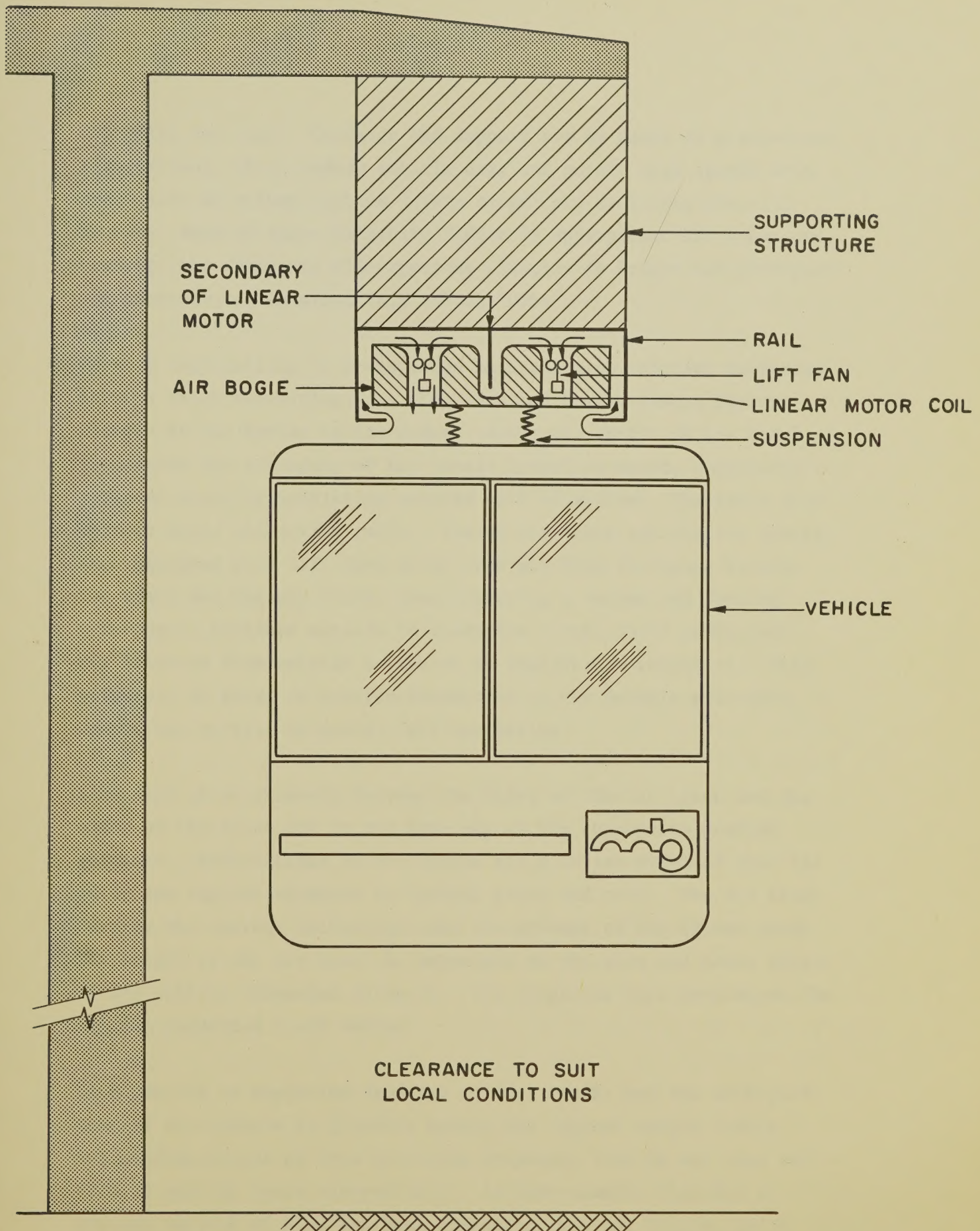
Discussion

The Safege system has several advantages. A completely enclosed track protects the roadway from weather thus maintaining adhesion to climb steep grades. This does not prevent condensation from reducing adhesion and does introduce the possibility of melting snow re-freezing into icicles below the beamway. The enclosed track is also a help in reducing the external noise level. Being suspended, the vehicle will bank at curves relative to its speed and the curvature. This is an important advantage over systems which require a fixed superelevation at curves, but this advantage becomes significant only over speeds beyond those of urban transportation with its close station spacing.

Disadvantages of an underhung monorail are the height of the structure necessary for highway clearance and the increased cross section required for tunnels. The Safege system appears more appropriate for longer journeys such as airport feeders than for urban transport.

4. Tracked Air Cushion Vehicles

TACV's are under development in France, Britain and the U.S.A., mainly for high speed intercity service, with proposed speeds up to



SCHEMATIC DIAGRAM OF URBA SYSTEM

250 miles per hour. Guidance and support are by means of pressurized air cushions, which reduce vehicle drag and permit high speeds with propulsion by either turbine driven propellers or linear electric motors. None of these intercity TACV's is appropriate for urban use; however, the Compagnie d'Energetique Lineaire in France has developed and demonstrated an urban TACV called "Urba".

Urba is very similar to a suspended monorail with vehicles supported below a track consisting of a wide inverted U with inward-facing flanges at the bottom of the sides. Along the center of the track is mounted the secondary of the linear induction motor, comprising a vertical strip of insulation covered with aluminium. The track also carries power collection rails. Inside the track run the air trucks, each equipped with lift fans which draw air from the space between the track and the air truck, hence creating a vacuum and forcing atmospheric pressure outside to float the truck, until sufficient air flows in from outside to create an equilibrium condition. This principle is known as Suction-Suspension or the Dynavac principle, and is the reverse of normal TACV suspension.

Secondary guide chambers between the sides of the air truck and the sides of the track act in the same way as the support to provide guidance. Restrictions to the inward air flow are provided into all guide and support chambers to control pitch and roll. The air truck carries the current collections and the primary of the linear motor. The length of the air truck is dependent on the size and hence weight of the vehicle suspended below it. Its length in turn determines the minimum permitted track radius.

Each vehicle is supported from two or more trucks and the configuration of the vehicle is flexible within the support weight limits. Two configurations of Urba have been proposed, Urba 30 and Urba 100 with 30 and 100 seats respectively. An experimental line for a smaller version of Urba has been operating in Lyon, France, and a study is underway for a full scale line in Rouen.

Discussion

The Urba system is very similar in form to the Safege monorail, it has the same advantages and disadvantages including a relatively complex switch. However, the air truck is much simpler than the rubber tired Safege truck and the linear motor further simplifies the mechanical equipment. Urba is a new concept in urban transit, first proposed in 1965 and it is premature to make a detailed evaluation of the system. However, the concept shows considerable promise and merits further investigation. The TACV very high speed systems would not be suited to rapid transit as envisaged for Hamilton, since the station spacing contemplated would not be long enough to develop the potential velocities.

5. Bus Rapid Transit

One of the problems of urban buses is the low speeds resulting from congested streets. Solutions to this problem range from reserved bus lanes on streets to an entirely separate right-of-way. The advantage of using standard buses is the low equipment cost, the ability to use existing bus companies' maintenance facilities and operators, and the ability for the bus to leave its right-of-way in both the suburbs and city center, providing direct service without any transfer.

The guideway for buses is basically a two-lane road with pull overs at stations. The road can be at-grade, elevated or in tunnel; however, in this latter case quite extensive ventilation will be required. One possible way to avoid this would be the use of electric trolley coaches. Although no trolley coaches are presently manufactured in North America, current concern with air pollution makes it likely that certain existing systems will be retained. They are widely employed in the Hamilton system and Toronto is having 150 buses rebuilt by Western Flyer Company in Winnipeg. Therefore it is anticipated that new buses will continue to be made available. Trolley coaches also have the advantage of higher

power to weight ratios than existing diesel buses already mentioned as a limitation on diesel buses for use on long grades. Despite the lack of flexibility provided by trolley coaches with their overhead wires, they should not be discounted should bus rapid transit appear desirable.

The basic concept of bus rapid transit - standard buses on a private guideway - suffers from the high labour costs associated with an operator on each bus and from the need for a wide two-lane guideway which is estimated to cost more than a Duorail alignment. Technical developments have been proposed to automatically steer and control buses and while this would add considerably to the basic price of an urban bus it would reduce both labour costs and the width of the guideway. Such control is envisaged using buried electrical conductors in the roadway, a mechanical restraint would be needed to prevent failure in the electrical guidance creating an accident hazard. While a prototype bus has been demonstrated with automatic steering and control no mechanical restraint has been provided.

Discussion

Bus Rapid Transit, in its simplest form, uses conventional technology with all the drawbacks of existing diesel buses except delays due to street congestion. The required guideway has the advantage of being available for use by emergency vehicles such as fire engines and ambulances. The more advanced concepts of automatic steering and control have not been developed to a point where they can be technically and economically evaluated.

SOILS REPORT

PETO ASSOCIATES LIMITED

Hamilton Area Rapid Transit
An Appreciation of Route Soil Conditions
for
De Leuw Cather & Co. of Canada Ltd.
Consulting Engineers

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JOB NO. 70-C47

JUNE, 1970



PETO ASSOCIATES LTD.
CONSULTING SOIL ENGINEERS
1287 Caledonia Rd. Toronto 19 · Ontario · Phone: (416) 789-1126

JOB NO. 70-C47

June 29, 1970.

De Leuw, Cather & Co. of Canada Ltd.,
133 Wynford Drive,
Don Mills, Ontario

Attention: Mr. M. P. O'Brien

Gentlemen:

Re: Hamilton Area Rapid Transit Study
An Appreciation of Route Soil Conditions

We submit herewith an engineering appreciation of the soil and groundwater conditions along six possible route alignments.

This work was performed in accordance with your directions issued on the 8th June 1970, and amended subsequently from time to time as the work progressed.

We also enclose as an appendix certain unit prices for a 21 foot ovoid shaped tunnel on rock constructed for Ontario Hydro at Nanticoke.

We believe we have complied with your terms of reference, however, we shall be pleased to discuss any points you may wish to raise.

Yours very truly,

PETO ASSOCIATES LTD.

(Signed by)

C.F. Freeman, P.Eng.,
Chief Engineer.

CFF/vs



Hamilton Area Rapid Transit
An Appreciation of Route Soil Conditions

INTRODUCTION

The study reported on herein was authorised by Mr. J. Spiegelman, P.Eng. of De Leuw, Cather Co. of Canada Ltd.

A feasibility study of the physical engineering problems related to the installation of a rapid transit system required an appreciation of the soil engineering conditions along certain suggested routes.

Peto Associates Ltd. was authorised by Mr. J. Spiegelman, P. Eng. on the 8th June 1970 to undertake this appreciation on behalf of De Leuw, Cather & Co. of Canada Ltd. and submit a report by the 30th June 1970.

The routes under consideration are shown on Fig. No. 4 together with a series of geological sections depicting the various soil strata and general groundwater levels applicable to each route. The sections are subdivided into their various geological environments; these are superimposed on each section.

Fig. No. 1 is a perspective outline of the bedrock topography underlying the area under consideration; it is shown as an aid to understanding the influence of the bedrock topography on the stratigraphy of the soil overburden and it's attendant soil engineering characteristics.

Fig. No. 2 illustrates the geological formation of Hamilton "Mountain".

Fig. No. 3 outlines typical sections of the various types of structure proposed along the routes.

The appreciation is divided into two main headings. The first being the geology of the area and the second the engineering interpretation and appreciation which logically follows on from the geological background of the area under consideration.

URBAN GEOLOGY

The Hamilton area has been subjected to a number of geological processes which have shaped the environment to the form we see today. A short description of these processes will show how the engineering characteristics are affected by the geological past. See Figs. 1, 2 & 4.

1. BEDROCK

The bedrock which underlies Hamilton north of the mountain is red Queenston shale. This is a medium hard compaction shale which requires blasting for removal at depth. This rock is perhaps 350,000,000 years old. On top of the mountain, the Queenston shale is overlain by a series of younger rocks, consisting of mainly dolomites, in some cases interbedded with grey shales. Differential erosion has removed the cap rocks over the Queenston shale, leaving us the ± 300 ft. escarpment, known as the "Hamilton Mountain".

Erosion also formed a deep valley in the bedrock, just west of Hamilton, under what is now known as Cootes Paradise, extending south towards Dundas. This is known as the Dundas Valley, and extends over 400 ft. in depth. Another deep valley, approximately 150 ft. in depth was eroded at the base of the Mountain, evidently feeding a preglacial river westwards into the valley.

Thus, the bedrock surface is extremely variable. The 300 ft. $\pm$ high Hamilton Mountain drops off into a deep east-west valley, which then feeds into the Dundas Valley. The rock rises again under the central part of Hamilton in the form of a rock plateau, then drops away quickly under the present Lake Ontario. Figure #1, shows a diagrammatic sketch of this bedrock topography.

2. OVERBURDEN SOILS

During Pleistocene times, glaciers advanced out of the Lake Ontario basin, climbed up over the mountain and left a deposit of glacial till over the area. This

till is dense, and generally silty in texture. The glaciers then retreated, and the area was invaded by a large glacial lake. This lake left thick deposits of silts and clays, filling up the deep valleys and areas below the mountain. It is surmised that the glaciers advanced 2 or 4 times, and thus left a series of tills, interstratified with clays and silts.

Within the bedrock valleys, the clays and silts tend to be hard and dense. However, under Lake Ontario the clays are much softer, and quite deep.

Finally, the last glacial lake, Lake Iroquois, deposited a stratum of offshore sands and silts over the surface, just before this lake drained. Man has then placed a variable mixed fill over much of Hamilton in the course of various constructions, developments, etc. Much of the land along and north of Burlington Avenue is reclaimed land.

3. MOUNTAIN SLOPES

The soils plastered onto the Mountain face are quite heterogeneous and dangerous from an engineering viewpoint. The slopes are in a delicate state of equilibrium, and in fact movement is currently being monitored in some areas. Thus, work on the slopes must proceed with the utmost caution and planning to avoid further slope movements.

4. GROUNDWATER

Groundwater probably emerges from recharge zones south of the mountain; emanates as springs near the base of the mountain, and/or feeds into the bedrock valley, to exit into the deeper Dundas Valley and hence under Lake Ontario. This is probably the regional flow of the deeper groundwater regime. Another groundwater system, probably of more immediate concern is perched within the offshore sands near surface. This, in all likelihood, drains into Lake Ontario.

5. SUMMARY OF GEOLOGY

On the basis of this geological setting, the areas which the proposed subway lines will cross may be subdivided as follows:

- a) Bedrock Environment - Tunnelling through the mountain, intersecting dolomites, shales and sandstones over Queenston shale.
- b) Mountain Slope - An unstable environment of a talus-till soil complex.
- c) Valley Environment - Stratified soils of sands, silts and clays, very stiff to dense over bedrock ± 150 ft. down.
- d) Rock Plateau - Area of Central Hamilton, where bedrock is within 20 ft. to 40 ft. of surfaces and overlain by wet sands over glacial till.
- e) Lake Environment - An area of deep, soft lacustrine clays and silts ± 100 ft. thick over bedrock.

ENGINEERING APPRECIATION

Routes 2 and 4 are the two separate main North/South legs, which form a common alignment with all routes along Burlington Street, from a point just east of Wellington Street.

Accordingly, these two routes will be dealt with separately and will form the basis of the engineering appreciation for the six routes under consideration.

The short interconnecting links between routes 2 and 4, which together with routes 2 and 4, form routes 1, 3, 5 and 6, will be commented on separately under their various route designations.

ROUTE 2

Starting at Fennell Avenue at the intersection with Upper James Street, this route is in tunnel section to about the intersection with St. Josephs Drive, where cut and cover construction is adopted.

Cut and cover construction is followed to Murray Street approximately where the transition starts to take the route on to an elevated structure over the CNR tracks between Strachan and Stuart Streets.

The route remains on elevated structures from this point to the terminal point on Burlington Street, just east of the intersection with Kenilworth Avenue.

TUNNEL SECTION: Fennell Avenue to St. Josephs Drive:

This length is wholly in bedrock in Hamilton Mountain consisting of the Queenston Shale overlain by dolomites, which in some cases are interbedded with grey shale and sandstone. See Fig. 2.

The following observations are applicable to all the route tunnel sections in rock.

The bedrock is overlain by a relatively shallow layer of firm to stiff clayey and silty tills 12 to 25 ft. thick.

Some groundwater can be expected in the soil overburden and the bedrock, but generally this is not expected to be beyond conventional pumping requirements.

The bedrock can be regarded as competent from the point of view of support, and stress release problems in regard to the tunnel lining, in general, are minor. However, it is to be expected that the frequency of rock bolting will be greater in the dolomite and shale formations, overlying the red Queenston shale.

In this respect, the Cabot Head formation is the poorest and softest rock encountered in the tunnel sections.

Groundwater flow of a seepage nature in the bedrock will be confined mainly to the formations overlying the Queenston shale, with the main concentrations being expected along fracture zones within the competent rock strata.

Conventional horseshoe section for the tunnel shape is acceptable.

Sinking the shaft through the overburden can follow conventional shoring procedures, with some provision for the removal of seepage water.

Lastly, care should be taken in the design and construction of the tunnel sections to avoid endangering any of the existing and projected structures related to the CHARM project.

CUT & COVER SECTION: St. Josephs Drive to Murray Street:

The rail level at St. Josephs Drive is elevation 360 dropping to between elevation 300 and 275 along McNab Street.

From St. Josephs Drive to about Mulberry Street the alignment is in the preglacial valley environment where the soils are mainly firm to stiff clays and silt tills, covered by loose to dense sands and fills.

The bedrock is the Queenston shale at depths of ± 150 feet. Groundwater lies about 15 to 20 feet below grade. It is perched above the stiff clay till found about 30 ft. below grade.

Construction here requires excavation to depths of about 40 feet below grade, which entails working below the groundwater table in the loose to dense sands within a built-up and heavily serviced area.

Conventional soldier pile with lagging is not considered practical without lowering the groundwater table and possible loss of ground.

Driven steel sheet piling, with the use of jetting is a possibility, however, some lowering of groundwater could occur together with loss of ground.

Accordingly, it is considered that mud slurry trench construction will be necessary in order to provide adequate safeguards for the existing buildings and services.

However, even this method although it provides a solution to the soil problems, does present some practical difficulties in regard to access at locations where there are heavy concentrations of underground services, particularly at intersections.

Alternatively, where the mud slurry trench technique cannot be used, freezing the subgrade may be considered as a solution.

The shoring for the concrete walls formed in the mud slurry trenches may be braced by the use of soil anchors drilled into the stiff clay.

Adequate bearing of between 4 to 6 Kips per sq. ft. is available at the proposed foundation grade in the stiff clay.

In general, the excavated granular materials may be used as backfill, this may include portions of the cultural fill, but selection will be necessary. Excavated clay material is not recommended for backfill, although it may be possible to use some of it under certain controlled conditions and locations.

The construction problems related to cut & cover construction below groundwater level may be very much reduced, if not completely eliminated along the North/South leg of route 2, by the adoption of an elevated structure.

The foundations for such a design could be spread footings founded in the sand stratum where this was of a suitable density and above the water table. Alternatively, where such a condition was too deep to be economical for spread footings, or below the groundwater table, driven pedestal type concrete piles may be adopted. These also would normally be founded in the sand deposit and probably limited in depth to ± 40 ft.

In the event that neither of these solutions proved to be practical, augered and lined caissons, belled in the stiff clay or clayey silt arising between depths of 35 to 80 feet may be adopted.

Spread footings founded in the compact to dense sand could be designed for allowable bearing values of 4 to 7 ksf.

The order of working load for the driven pedestal type concrete piles would be 100 to 300 kips.

Augered caissons founded on the clay or clayey silt could be designed for allowable bearing values of 10 to 20 kips/sq. ft. depending on depth.

From Mulberry to about Colbourne Streets, there is a geological environment change from glacial valley to Rock Plateau; the proposed construction mode is still cut and cover.

The soils in this area consist essentially of loose to dense silty sands, approximately 20 feet thick on a shallow veneer of stiff clay till overlying the Queenston shale bedrock which is 25 to 40 feet below grade.

The groundwater is perched in the sands and occurs at 10 to 15 feet below grade.

The construction procedures are similar to those already described, except that the bedrock will come very close to, if it does not form part of, the founding grade.

Adequate bearing is also available and should not present a problem.

Comments in regard to backfill are similar to those already given.

From about the Barton Street area to Murray Street there will be a transition zone where the cut cover structure changes to an elevated structure.

Geologically, the environment in the Barton-Murray Streets area changes for the last time, and is designated as the Lake Environment; this condition is maintained to the terminal point of this route just east of Kenilworth Avenue.

From here to about the Colbourne Street-Burlington Street intersection, the soils are loose to dense silty fine sands, about 20 feet thick, overlying compact to dense, slightly clayey silts, which extend to between 35 and 45 feet below grade.

Below this crust of loose to dense soil there is a deep deposit of firm to soft, lacustrine, saturated clay which is normally to lightly overconsolidated. The depth to bedrock is not known but can reasonably be expected to be 100 ft. or more below grade. It may or may not be covered by a layer of dense till.

The water table arises in the silty fine sands at depths of between 12 to 15 feet. In the transition zone from cut & cover to elevated structure, it would seem to be essential to maintain some form of the cut & cover structure, at least until the roof rises above the water table, at which point and subject to local structural

foundation requirements, the standard earth cut to earth fill sections may be adopted. See Fig. 3.

The structure over the CNR tracks and the piers for the elevated structures probably can be founded on short driven pedestal piles designed for loads of 100 to 150 kips and founded in the silty sand overlying the silt.

This type of foundation may be adopted for the elevated structure for the section of the route extending to about the intersection of St. Catharine and Burlington Streets.

Beyond this point, eastwards to the terminal point of this route, and all other routes, the soils consist of layers of fill, sand, silt and clay down to a depth of about 20 ft. They vary in density and consistency and are unreliable as load bearing media for the type of structure under consideration.

In addition, there are numerous embayments or inlets, which, in a transverse direction, pierce these upper lacustrine deposits completely and contain deposits of very organic soil and heterogeneous fill.

Below, these upper layers and the organic deposits, there is the same deposit, already referred to, of firm to soft lacustrine, saturated clay. Where it has been completely penetrated by borings it extends to about 80 feet below grade, where there is either a dense silt/sand till overlying the shale bedrock, or bedrock without the covering of till.

The bedrock which is the Queenston shale appears to occur at ± 100 feet below grade, except near the extremity of the route where it rises to within 50 feet of the existing grade.

The groundwater table is related to Ontario Lake level and generally arises within 10 feet of existing grade.

The soil conditions necessitate the use of some form of pile or caisson foundation to support the piers for the elevated structures.

Concrete filled 16-inch diameter steel tube piles driven to virtual refusal in the dense silt till or onto the bedrock should be capable of supporting 120-ton working loads.

Steel H-piles equivalent to 14' x 14½' CBP 145 may also be used in place of the steel tube pile.

Alternatively, augered caissons belled into the dense silt till may be adopted using a bearing value of 30 kips/sq. ft. These will need to be installed using a steel liner and because of the possibility of necking the caisson should be provided with a thin steel shell within the augering liner tube.

This liner will also afford protection for the shaft concrete against sulphate corrosion of the concrete.

ROUTES 3 & 4

St. Josephs Drive to Wilson Avenue:

Here the geological environment is similar to that described for Route 2; however, borings in this vicinity are scanty; the information available is confined to the northern side of the buried valley, which is thought to be smaller and possibly shallower than that outlined for route 2.

In view of the similar geological background, partially conformed by soil conditions, it may reasonably be assumed that conditions similar to those described for route 2 will apply in this area.

At locations where borehole information is available, groundwater, which is again perched in the sand stratum, arises at depths of 10 to 15 ft. from grade.

The structure proposed on this route is elevated throughout and where spread footings cannot be placed directly on the rock near the mountain tunnel portal, bearing values of at least 4 to 6 kips/sq. ft. should be available within 20 feet of grade.

In general, it would seem that driven concrete pedestal type piles could be founded on a suitable stratum within 50 feet of existing grade. At this stage working loads of 100 kips may be assumed for such piles.

Where, a suitable stratum is not available within this depth range, augered caissons could be adopted as an alternative in order to pick up a suitable bearing stratum at reasonable depth.

From Wilson to Barton Streets:

Here the Rock Plateau environment is encountered.

The Queenston shale bedrock occurs within 15 to 40 feet along this section and is covered by a veneer of dense clayey silt till, overlain by loose sand or fill.

The groundwater where encountered is perched above the till in the sand. It is of a seepage and seasonal nature only and should not present any abnormal construction problem.

The structural footings may be founded directly on the dense till or on short driven concrete pedestal piles founded on the till or the bedrock. Such piles should be capable of supporting 100 to 300 kips.

Barton Street to Burlington Street:

This section of the route is in the geological Lake Environment, however, as may be expected there is a short length north of Barton Street, extending possibly as far as Birge Street, where there is a transition from the Rock plateau to the Lake environment.

Generally, the soil conditions from Barton Street to Burlington Street are similar to those arising along the length of Burlington Street between Victoria Avenue and Kenilworth Avenue. This latter length is common to all the routes.

They consist of fill and/or loose to compact offshore sands extending to about 15 feet, and overlying a deep deposit of soft to firm lacustrine clay. The bedrock is ± 100 feet below grade.

Within the transition zone from Barton Street to Birge Street the structure would probably be supported on driven pedestal type concrete piles founded on either the dense till or bedrock, where this is within 50/60 feet of existing grade. Beyond this point, e.g. north of Birge Street to the terminal length of the route structure support will be similar to those described for this section of the route under Route 2, in fact all comments previously made for Route 2, naturally will apply to this section of Routes 3 & 4.

ROUTES 5 & 6 - Connecting Link Between Routes 4 & 1&2:

This section extends from the tunnel portal area on the northern slopes of Hamilton Mountain, where rail level is at $\pm$ elevation 375 to about Bold Street, where the rail level is at elevation ± 300 .

This section is located in the buried glacial valley environment, where the soil conditions are similar to those already described for the corresponding lengths of Routes 1-2 & 3-4.

Thus, for cut & cover structures, there will be a construction problem in regard to groundwater control, since the excavation will be below groundwater level, which arises in the overlying sands and fills at depths of 10 to 20 feet below grade.

This problem has been discussed under the sections dealing with Route 2.

Likewise, adequate bearing for the proposed cut & cover structures should not present any problem because (i) the weight of the displaced volume of soil is greater than the structure and (ii) the soil at the founding elevation, because of its geological history, can be expected to provide adequate bearing.

It would seem likely that the construction problem in regard to groundwater control could be very much reduced if not virtually eliminated by abandoning the proposed cut & cover section in favour of an elevated structure.

ROUTES 1 & 6 - Connecting Link Between Routes 2, 5 & 3&4:

This section leaves Routes 2, 5 at the intersection of Vine & McNab Streets and joins Routes 3, 4 at the intersection of Barton Street and Ferguson Avenue.

It lies almost wholly in the zone designated geologically as the Rock Plateau.

Soil and groundwater conditions therefore may be expected to be similar to the lengths of Routes 2&5 & 3, 4, where they traverse the same environment.

The route is designed as cut & cover from McNab Street to about the intersection of Cannon and St. Catharine Streets; from this latter point up to the point of juncture with Routes 3 & 4 on elevated structure, there is a transition zone from cut & cover structure to elevated structure.

Apart from the construction problem related to the control of groundwater already referred to under Route 2, there does not appear to be any other serious or difficult soils problem to be overcome in building this section of the route.

Foundations for the elevated length would probably be founded on pedestal type, driven concrete piles founded on the bedrock, or the overlying dense till, where this is found within 50 to 60 feet of existing grade.

Summarising the foregoing, the following conclusions are warranted:

1. The tunnel sections confined to the Hamilton Mountain lengths of the route do not appear to present any abnormal construction problems for work in rock.

Precautions will be necessary where tunnels pass beneath structures constructed on the northern slopes of the Mountain for the current CHARM project, particularly during the construction phase when blasting may be taking place.

2. Cut & Cover sections applicable to Routes 1, 2, 5 & 6 present a construction problem in regard to the control of groundwater, since they involve excavation to depths appreciably below groundwater level.
3. In the areas described geologically as buried glacial valley and rock plateau environments, where the cut & cover design presents groundwater control construction problems, the difficulties anticipated may be very much reduced, if not completely eliminated by resorting to an elevated structure design.
4. The soil conditions from a bearing aspect are poor in the area described geologically as the Lake Environment.

The structures in these areas are generally of an elevated type and will need to be supported on some form of driven displacement pile or on lined and belled caissons founded on dense till or Queenston shale bedrock.

The former deposit where encountered occurs at depths of ± 75 feet, whilst the bedrock occurs at depths of ± 100 feet below grade.

5. All routes in the buried glacial valley and/or the rock plateau environment, and designed as elevated structures generally can be supported on spread footings or driven pedestal concrete type piles founded within 20 to 60 feet of existing grade. Usually, the driven pedestal pile provides a solution to a construction groundwater control problem.
6. The groundwater in the area of Hamilton traversed by the proposed routes is in many cases aggressive in regard to attack on concrete.

Accordingly, Type II cement is recommended for all structures founded below the groundwater table and in certain cases the use of Type V sulphate resisting cement is essential.

Yours very truly,

PETO ASSOCIATES LTD.

(Signed by)

C.F. Freeman, P.Eng.,
Chief Engineer.

CFF/vs

A P P E N D I X A

Tunnel in Thinly Bedded Limestone
at Nanticoke, ONTARIO
for Ontario Hydro Electric Commission

Tunnel in Thinly Bedded Limestone
at Nanticoke, ONTARIO
for Ontario Hydro Electric Commission

This tunnel with the configuration given in the appended sketch is currently being excavated in thinly bedded limestone, at a rate of 30 ft./day using 3 shifts, each producing 10 ft./8 hour shift.

The range of prices quoted for the principal items of work is as follows:-

<u>ITEM</u>	<u>RATE</u>
Rock Excation	\$475 to \$680 lin. ft. of tunnel
There is 550 cu. ft. of rock excavation/lin. ft. of tunnel including 10% overbreak	
Concrete Lining	\$455 to \$530/lin. ft. of tunnel
In Rock Bolted supported section there are 4 cu. yds. of concrete/ lin. ft. of tunnel	
In Shot-Crete supported section	\$455 to \$590/lin. ft. of tunnel
Provisional Items	
Rock Bolts ungrouted	
10'0"x1½" diameter	\$2.90 to \$5.90/bolt
Wire fabric	\$1.00 to \$1.60/sq. ft.
Shot Crete 3-inch av. thickness	\$73.15 to \$150/lin. ft. of tunnel
Rate per cu. yd. of shot-crete	\$100 to \$120/cu. yd.
Steel Supports	\$0.80 to \$2.05/lb.
Grouted Rock Bolts	
10'0"x1½" diameter	\$7.75 to \$9.00/bolt

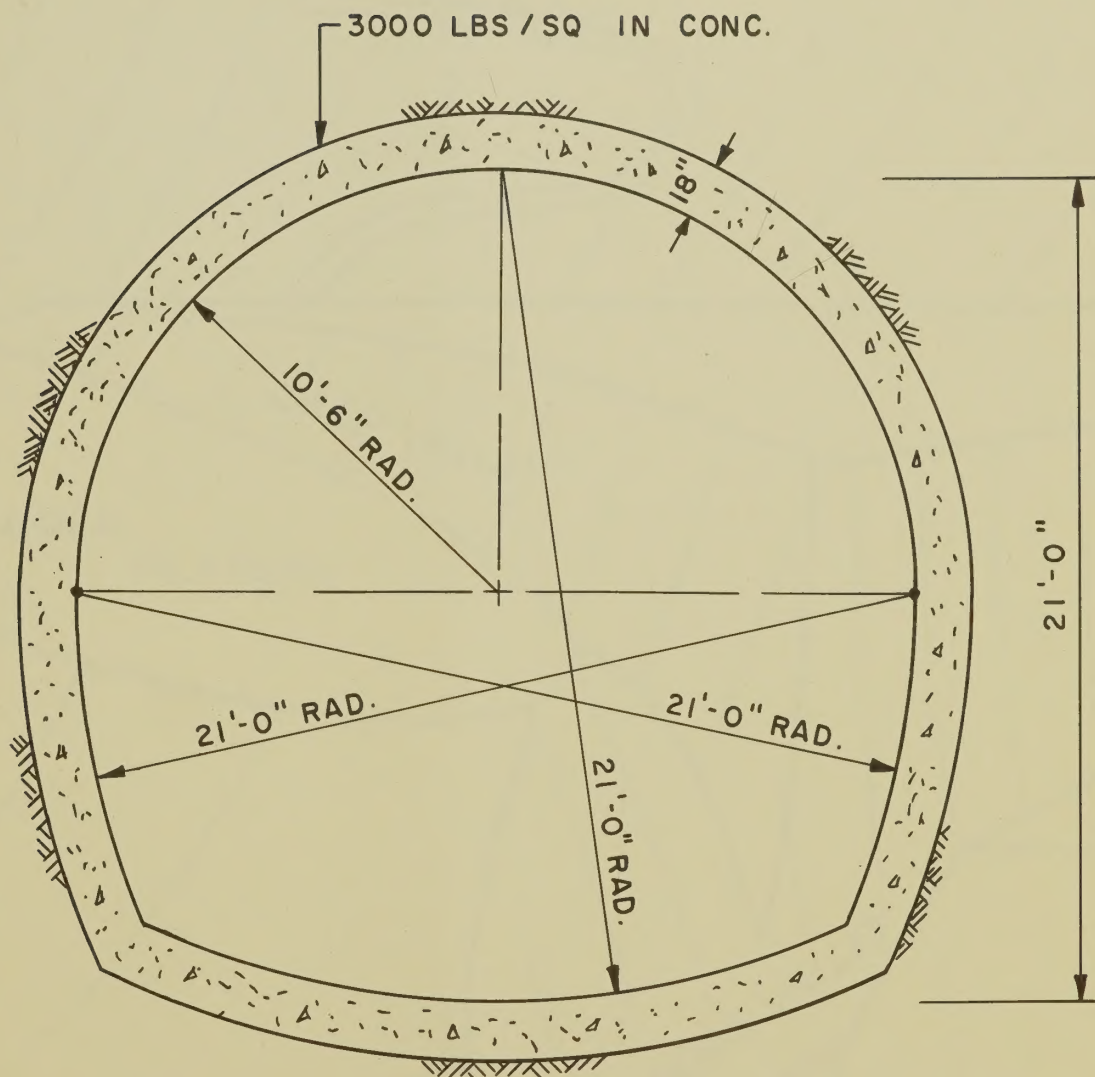
Estimated average cost of tunnel \$1100.00/lin. ft. of tunnel

Tunnel Length 1830 ft.

No Horizontal Bends, but two vertical bends

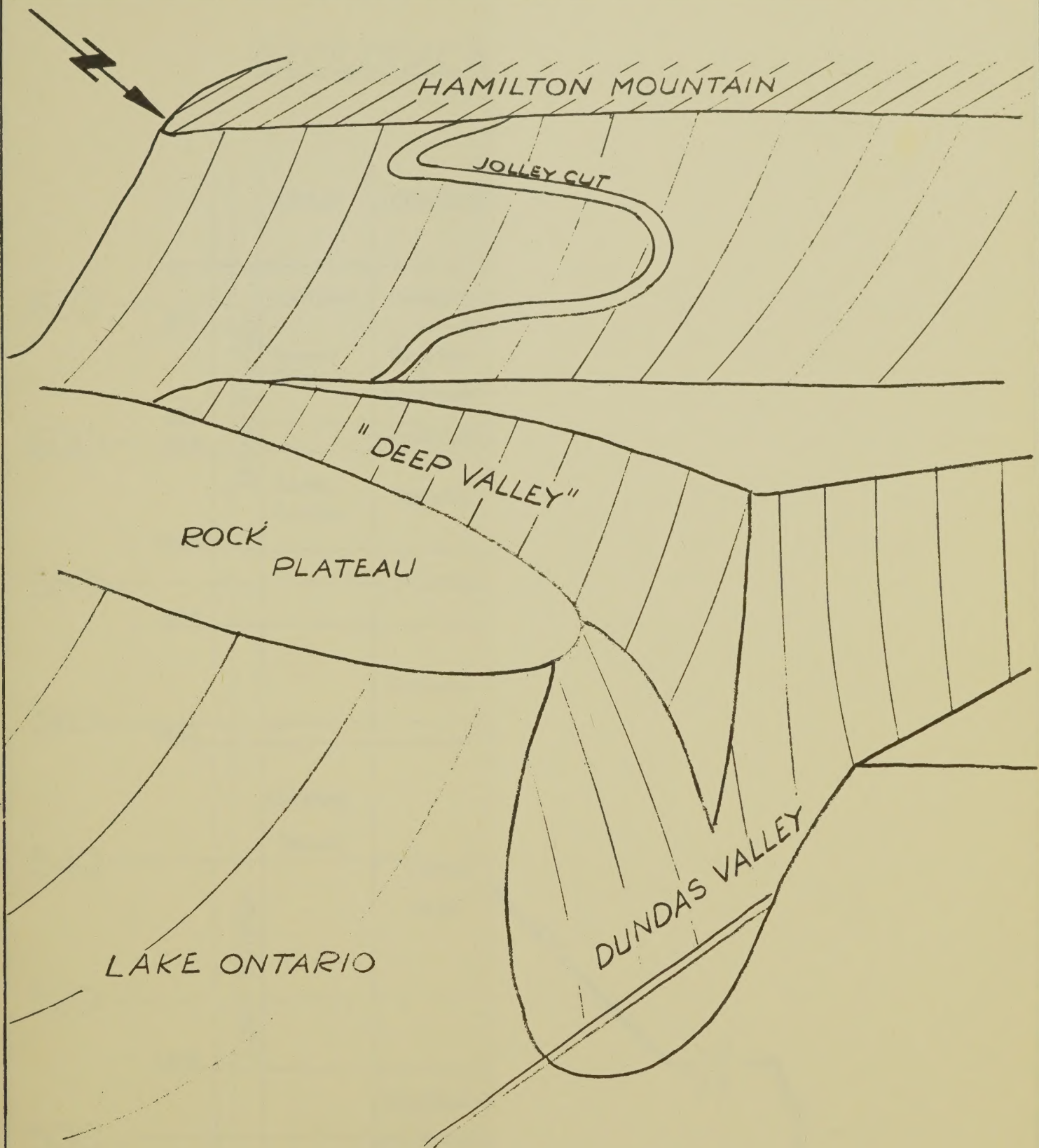
The tunnel invert elevation is 380.

The bedrock surface elevation is 540/570.



SCALE : 5' TO 1"

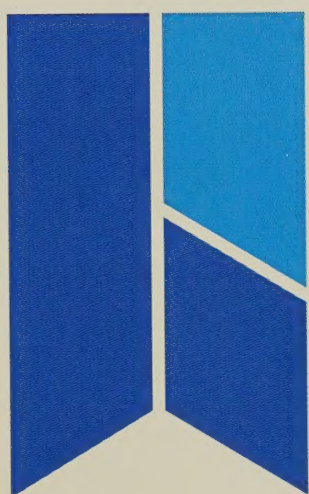
ONTARIO HYDRO TUNNEL
IN THINLY BEDDED LIMESTONE
NANTICOKE , ONTARIO



SKETCH SHOWING MAIN INTERPRETED
BEDROCK TOPOGRAPHIC FORMS

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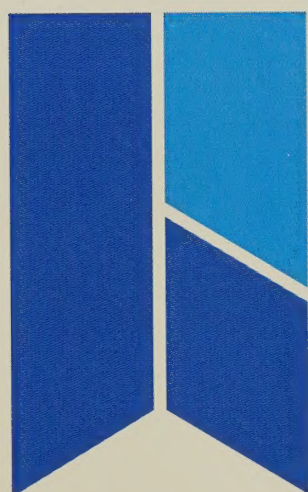


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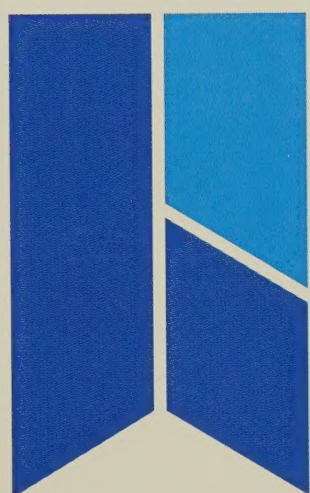


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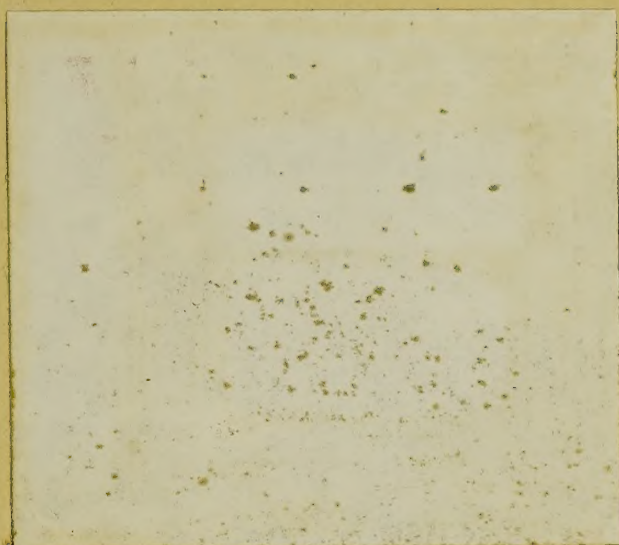
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